


BULLETIN
of the
American Association of
Petroleum Geologists

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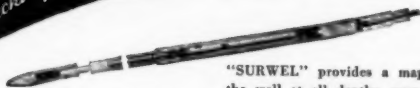


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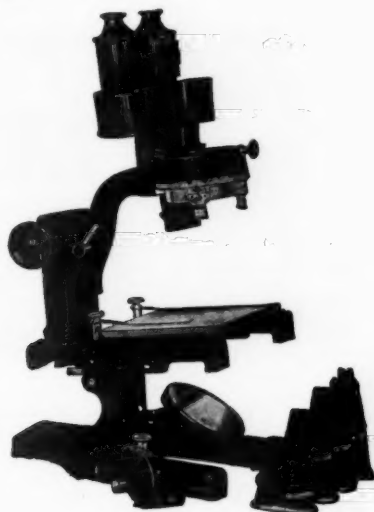
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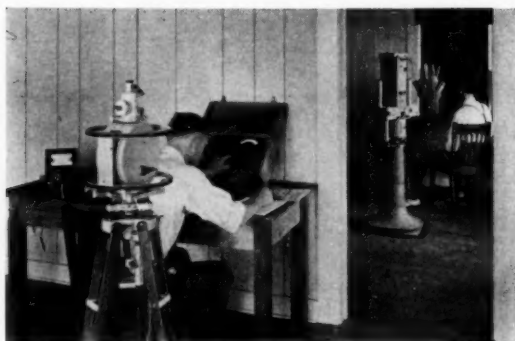


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BULLETIN
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JUNE, 1937

DISCOVERY RATES IN OIL FINDING¹

WALLACE E. PRATT²
Houston, Texas

ABSTRACT

A statistical review of oil-field discoveries by periods, the progressive accumulation of petroleum reserves, and the classification of discoveries according to method by which discovery was made, indicate a decreased discovery rate in recent years. Possible explanations for this decreased rate are discussed.

On several occasions during the past 15 years committees in the petroleum industry have deliberated on the question of the adequacy of the reserves of petroleum remaining unmined at the time, as against our probable future needs. Such committees have commonly realized that a factor more important for their purposes than the volume of the known or proved reserves is the volume of oil that may be added to the known reserves through future discoveries. Yet, because of the paucity of evidence bearing on discovery probabilities, reports on studies of this character have omitted any quantitative estimate for future discoveries. Quite generally investigators have voiced the secure belief that additional discoveries would be forthcoming in requisite number, but they have uniformly failed to support their belief with convincing proof. I have examined the record of past discoveries in the hope that in it some trend or other characteristic might be identified which could be brought to bear directly on the problem of gauging future discoveries. This inquiry has afforded no secure criterion for the estimation of the volume of future discoveries, but it has thrown a revealing light on the character and the accomplishment of this discovery effort up to the present time.

More than 30 billion barrels of oil had been discovered in the United States to the end of the year 1935. This figure represents the

¹ Read before the Association at Los Angeles, March 17, 1937.

² Vice-president, Humble Oil and Refining Company.

amount already produced plus that still present in known, proved natural reservoirs, underground. In the latter category, our underground reserves, there are estimated to be some 13 billion barrels. Roughly, nine-tenths of this total volume was found in the last 35 years of the period. The American experience throughout this period is analyzed by 5-year periods in the following table, which was compiled by John V. Boyce, and originally presented in slightly different form in a paper I read, in May, 1935, before the Chamber of Commerce of the United States, at Washington, D. C.

TABLE I
AVERAGE ANNUAL DISCOVERIES BY SUCCESSIVE FIVE-YEAR PERIODS IN THE UNITED STATES AS A WHOLE AND IN THE IMPORTANT PRODUCING STATES, CALIFORNIA, OKLAHOMA, AND TEXAS

| Period | CALIFORNIA | | OKLAHOMA | | TEXAS | | UNITED STATES | |
|-----------|---------------------------|-------------|---------------------------|-------------|---------------------------|-------------|---------------------------|-------------|
| | Millions of Barrels | Per Cent | Millions of Barrels | Per Cent | Millions of Barrels | Per Cent | Millions of Barrels | Per Cent |
| 1901-1905 | 35 | 0.6 | 135 | 2.5 | 55 | 1.0 | 345 | 6.3 |
| 1906-1910 | 110 | 2.0 | 65 | 1.2 | 2 | — | 300 | 5.4 |
| 1911-1915 | 45 | 0.8 | 180 | 3.3 | 105 | 1.9 | 435 | 7.9 |
| 1916-1920 | 185 | 3.4 | 140 | 2.5 | 110 | 2.0 | 660 | 12.0 |
| 1921-1925 | 305 | 5.5 | 90 | 1.6 | 210 | 3.8 | 875 | 15.9 |
| 1926-1930 | 435 | 7.9 | 290 | 5.3 | 1,225 | 22.3 | 2,165 | 39.4 |
| 1931-1935 | 25 | 0.5 | 100 | 1.8 | 395 | 7.2 | 725 | 13.2 |
| | 20.7 | | 18.2 | | 38.2 | | 100.1 | |

Table I fixes the discovery of the reserves in each important field as of the year during which the first commercially successful oil well was completed. The whole reserve at Kettleman Hills, for example, is credited to the year 1928, East Texas to the year 1930, and Conroe to the year 1931. In a small number of poorly defined producing areas such as Archer County, Texas, the extensions for each year are credited to the year in which they develop.

Perhaps the most arresting feature of this record of the progress of discovery is the fact that 40 per cent of all our oil was discovered within a period of only 5 years, 1926-1930. More than $\frac{1}{2}$ the total was found within 10 years, 1921-1930. A generally accelerated rate of discovery is revealed for the United States at large, and for each of the 3 most important producing states, throughout the first 3 decades of the period under review. In each case the rate of discovery reaches a conspicuous peak in the period 1926-1930 and falls abruptly thereafter. Through the years oil finding appears to have become more fruitful of results, measured in barrels of reserves discovered, until it

attained a maximum 6 or 8 years ago; thereafter its accomplishment failed suddenly and in marked degree.

It may be questioned whether the volume of reserves discovered constitutes a really significant measure of the success of oil finding. The task of discovering a small oil field is at least as difficult as the task of discovering a large one, and the discovery of a single large field may distort intolerably the record of barrels found. The discovery of the East Texas field, for example, is equivalent to the discovery of about 30 major oil fields, if only the volume of reserves in barrels is considered. Perhaps a better index of success in discovery effort would be, therefore, the number of new oil fields found rather than the number of barrels of reserves found.

TABLE II
MAJOR FIELDS DISCOVERED IN THE UNITED STATES AT LARGE AND IN
THE IMPORTANT PRODUCING STATES, CALIFORNIA, OKLAHOMA,
AND TEXAS, BY FIVE-YEAR PERIODS

| Period | CALIFORNIA | | OKLAHOMA | | TEXAS | | UNITED STATES | |
|-----------|-------------|-------------|-------------|-------------|-------------|-------------|---------------|-------------|
| | Num- ber | Per Cent | Num- ber | Per Cent | Num- ber | Per Cent | Num- ber | Per Cent |
| 1901-1905 | 1 | 0.5 | 3 | 1.5 | 5 | 2.5 | 10 | 5.0 |
| 1906-1910 | 2 | 1.0 | 1 | 0.5 | 0 | — | 5 | 2.5 |
| 1911-1915 | 1 | 0.5 | 5 | 2.5 | 7 | 3.6 | 18 | 9.2 |
| 1916-1920 | 4 | 2.0 | 5 | 2.5 | 5 | 2.5 | 23 | 11.7 |
| 1921-1925 | 8 | 4.1 | 6 | 3.1 | 15 | 7.7 | 40 | 20.4 |
| 1926-1930 | 11 | 5.6 | 12 | 6.2 | 24 | 12.2 | 59 | 30.4 |
| 1931-1935 | 4 | 2.0 | 6 | 3.1 | 15 | 7.7 | 41 | 20.8 |
| Totals | 31 | 15.7 | 38 | 19.4 | 71 | 36.2 | 196 | 100.0 |

Table II shows the number of major oil fields found since 1900 (through 1935) in the United States as a whole and in each of the important producing states, California, Oklahoma, and Texas. For the purposes of this compilation a major oil field is defined as one whose ultimate reserves are estimated at more than 20 million barrels. That is to say, any field large enough to supply the present national requirements for one week, or more, is classed as a major oil field. Nearly 200 such fields are included in the table. Their average size is more than 100 million barrels and collectively they account for nearly 80 per cent of all the oil discovered in the United States during the period.

The curve of discovery for oil fields, as indicated in Table II, takes on the same character as the curve of discovery for oil reserves shown in Table I, namely, a gradual rise through successive 5-year periods to a conspicuous peak in the half decade, 1926-1930, followed

by a sharp drop at the end. The experience in the 3 most important producing states duplicates that of the nation at large in this respect, leaving little doubt that, whatever may be the explanation, oil finding in the United States really passed through a maximum of accomplishment in the late 1920's.

Before inquiring into possible explanations of the character of the discovery record it may be pertinent to ask how the industry has gone about its job of finding oil in the past. What particular methods of exploration led to the discoveries? Perry Olcott has assisted me in a study of this problem, the results of which are shown in Table III.

TABLE III
MAJOR OIL FIELDS DISCOVERED IN THE UNITED STATES, DURING SUCCESSIVE
FIVE-YEAR PERIODS, CLASSIFIED AS TO METHOD OF DISCOVERY

| Period | (1) | | (2) | | (3) | | (4) | | (5) | | (6) | |
|-----------|-----|----------|------|----------|------|----------|------|----------|-----|----------|-----|----------|
| | No. | Per Cent | No. | Per Cent | No. | Per Cent | No. | Per Cent | No. | Per Cent | No. | Per Cent |
| 1901-1905 | 2 | 20.0 | 7 | 70.0 | 1 | 10.0 | — | 0.0 | — | 0.0 | 10 | 100. |
| 1906-1910 | 2 | 40.0 | 2 | 40.0 | 1 | 20.0 | — | 0.0 | — | 0.0 | 5 | 100. |
| 1911-1915 | 3 | 16.7 | 8 | 44.5 | 7 | 38.9 | — | 0.0 | — | 0.0 | 18 | 100. |
| 1916-1920 | 1 | 4.3 | 4 | 17.4 | 17 | 73.9 | — | 0.0 | 1 | 4.3 | 23 | 99.9 |
| 1921-1925 | 13 | 32.5 | 10 | 25.0 | 17 | 42.5 | — | 0.0 | — | 0.0 | 40 | 100. |
| 1926-1930 | 5 | 8.5 | 5.5 | 9.3 | 37 | 62.7 | 5.5 | 9.3 | 6 | 10.2 | 59 | 100.1 |
| 1931-1935 | 5 | 12.2 | — | 0.0 | 12.5 | 30.5 | 22.5 | 55.0 | 1 | 2.4 | 41 | 100.1 |
| Totals | 31 | 15.8 | 36.5 | 18.6 | 92.5 | 47.3 | 28.0 | 14.3 | 8 | 4.1 | 196 | 100.1 |

(1) Discoveries resulting from purely random drilling.

(2) Discoveries resulting from obvious evidences.

(3) Discoveries resulting from geological investigations.

(4) Discoveries resulting from geophysical investigations.

(5) Discoveries resulting from drilling deeper in territory already producing in shallow sands.

(6) Total discoveries since 1900 by 5-year periods.

The several categories of discovery methods in Table III require brief explanation. Column (1) is made up of the fields discovered by random drilling; that is, pure "wildcatting," with no logical basis to justify it. Column (2) contains all discoveries that have resulted from wells drilled on such obvious indications as oil and gas seepages at the surface or in shallow wells, and on less direct evidences, such as general trends, mounds over salt domes, or other points of uplift on constructional surfaces, paraffine dirt, and mineralized springs. No discovery of this character has been credited to geology in Table III, yet it is difficult to eliminate all geologic inference from the considerations that must have influenced the sponsors of these exploratory enterprises. In other words, it would be easy and perhaps logical to

credit geology with some of these discoveries. Column (3), geological discoveries, consists of all discoveries which resulted from geologic exploration, either surface or subsurface studies, including core drilling. Column (4) gives the list of geophysical discoveries, some of which, of course, were guided in part by geological studies. Column (5) shows discoveries resulting from deeper drilling in old fields. Such exploration, again, is often guided by geological studies, at least in part.

Table III may not be absolutely accurate in its classification by methods of discovery. Another inquirer might arrive at a slightly different result, but it is believed that the general trends would remain.

In comment on Table III, it may be observed that strictly geological studies are responsible for the discovery of nearly 50 per cent of the major oil fields found in the United States during the past 35 years, and that pure "wildcatting" has yielded only 16 per cent of the total harvest of major oil fields. Only 19 per cent of our major fields have manifested themselves at the surface with sufficient clarity to be identifiable except by an expert. If the effort we have put forth had depended solely on luck and obvious evidences, therefore, we would have found only 34 per cent of the major oil fields we have found during this 35-year period.

For the last 10 years the situation in this respect is even more striking. Our discoveries for the last 10 years number 100 major oil fields; more than the number discovered in the preceding 25 years. But only 4.6 per cent of these resulted from obvious evidences, and only 10 per cent were due to the random-drilling type of wildcatting. Geological studies maintain their total record of discovering 50 per cent of our major oil fields, and geophysical exploration, closely akin to geologic exploration, is responsible for 28 per cent of the major oil fields found during the last decade. If the results of geology and geophysics are combined, they include 78 per cent of our finding accomplishment during the last 10 years. Obvious surface evidences and random drilling together have revealed to us only 16 major oil fields (16 per cent of the total) within the past 10 years; less than half their previous contribution.

Perhaps more significant than the relative accomplishment of each method of exploration is their varying effectiveness with the passage of time throughout the period under review. Random drilling was important early, accounting for 30 per cent of the discoveries in the first decade of the period under review. It attained its greatest effectiveness in the half decade, 1921-1925, with a record of 13 major oil

fields in 5 years, 2.6 oil fields per year, equivalent to $\frac{1}{3}$ of the total number found. Drilling on obvious evidences was important in the early part of the period, also, yielding us 70 per cent of our discoveries in the first half-decade, 1901-1905. Thereafter it continued to furnish a large proportion of our major oil fields each decade until the last when, as stated already, its contribution fell to 4.6 per cent. Geological exploration, on the other hand, made little contribution to the accomplishment of the first decade and did not reach its maximum effectiveness until the period 1926-1930, during which it was responsible for the discovery of 37 major oil fields, an average of more than 7 per year. During the last 5 years its accomplishment has been sharply reduced to 12.5 major fields for the period, a rate lower than any it had shown since the 1911-1915 period. Finally, geophysics became a useful method of exploration only within the last decade, having no discovery to its credit previously. Nevertheless, for the last half-decade it has established a record of 22.5 discoveries of major oil fields, 55 per cent of the total accomplishment.

Possibly the tendencies suggested by Table III are not valid. Perhaps we shall again make a large proportion of our discoveries of major oil fields by random drilling or by drilling on or near obvious evidences of the presence of oil. Perhaps we shall again find as many as 7 major oil fields per year in the course of a 5-year period by geological exploration. But these possibilities seem unlikely. Most of the obvious oil fields appear to have been found, and the number of wildcat wells drilled at random has fallen off in recent years. Our geological discoveries are definitely fewer in number and constitute a smaller proportion of the total discoveries over the last 5 years. Only geophysics continues to maintain its accomplishment. All of the older methods combined have yielded us only 19 major oil fields in the last 5 years, a number smaller than the achievement of these methods for any similar period since 1915.

A rough gauge of efficiency in oil finding is the number of dry holes drilled per major discovery. If our only method of exploration were random drilling of wildcat wells this index would be more significant. Our recently improved methods of exploration in advance of drilling have enabled us to reduce the number of dry holes drilled per discovery. In the nation at large we have drilled about 1,000 dry holes for each major oil field we have found to the end of 1935. But in recent years this ratio has fallen markedly, until during the last 5 years it has averaged only 500 dry holes per major discovery.

In discussions of the stability of the producing industry, the suggestion that we could well do with a smaller volume of oil in proved

reserve is often advanced. Those who feel secure in our ability always to find more oil when we need it believe the present reserves to be excessive and burdensome. Considered merely as an inventory our reserves are undoubtedly heavy. No one likes to carry in stock all the raw material he expects to use during the next 10 or 15 years. But as a true reserve, to be drawn on only as needed, our underground storage constitutes no burden, and is not too large.

Another aspect of our reserves, apart from their adequacy as a supply for a certain number of years, has recently come to be realized. If oil is to be produced efficiently, that is, if recovery is to be reasonably complete and unit cost low, it must be produced at a rate slower than in the past. The optimum rate of production for a given pool depends, among other factors, on the size of the reserve. The rate of production necessary to meet our national needs has risen until our present reserves are hardly large enough to permit efficient production at the required rate. This fact is coming to be recognized despite our current ability to produce, temporarily, in excess of market demand. Some of our current production is being maintained at a wastefully high rate. This consideration makes it desirable to maintain our reserves at something like their present volume even though we could do with smaller reserves, so far as other purposes are concerned. We need all of our present reserve, or more, to permit efficient production at our present rate of consumption.

An economist would be tempted to explain the abrupt drop in discovery subsequent to 1930 as a result of the economic and industrial depression which began at the end of 1929. As a matter of fact, many of those with whom I have discussed the record in recent years have seized immediately upon this explanation, once they have accepted the record itself. Without doubt the depression slowed up exploratory work, and so tended to retard discovery. But 1935 was not a depression year so far as exploration was concerned; it could hardly have been more active. Yet discoveries for 1935 are small compared with the average discoveries from 1926 to 1930, inclusive. Again, the year 1936, although it is not included in the preceding tables, appears now to have yielded smaller total discoveries even than 1935, despite feverish activity in exploration. In the light of this evidence, the depression, alone, appears inadequate as an explanation for the slump in finding.

Moreover, when one analyzes the methods by which our discoveries have been made, and learns that our methods of finding oil have been gradually changing, and that our use of the old established methods seemingly reached the point of diminishing returns about the

time our discovery rate began to fail, the coincidence at once makes obvious another possible factor in our retarded discovery rate. Our persistence in searching for deeper oil in the regions already proved for production has forced us to rely more and more exclusively on geophysics as a guide to finding, as our older methods have failed us. Geophysics alone has not as yet proved equal to the task of finding as much oil as all our older methods combined formerly found. And so discovery rates have declined.

The conclusion would seem to follow that if we are to maintain our established record in rate of discovery, or even to find oil at a rate equal to the current rate of consumption, we must further improve our finding technique in the near future. Our recent efforts to this end have been directed toward the perfection of geophysical methods for determining structure at greater depth. But there is obviously a limit to the depth to which wells can be drilled. There is also a limit to the depth at which oil may be encountered even where structural conditions are favorable. This limit varies from one district to another, but many of our more deeply buried structures have recently been proved to contain gas instead of oil. As we drill still deeper, this tendency is more manifest. It is clear that we can not continue indefinitely to add to our reserves of oil merely by drilling to greater depths.

A. I. Levorsen, our retiring president a year ago, outlined a line of research more promising than deeper drilling as a means of improving our finding technique. He recommended geologic studies at once broader and more intensive than our old "structure hunting" methods, for the purpose of discovering what he designates "stratigraphic" pools; that is, pools of the East Texas type, where the reservoir control results from stratigraphic or "shore-line" conditions rather than from simple local deformation of the enclosing strata. Intensive studies in stratigraphy, sedimentary petrography, and paleontology, with the continued aid of geophysics, will become the working tools of this new technique. Many such pools are large, and, therefore, are worth finding, but it should be recognized that in the search for them the exploration must be carried out largely by the actual drilling of wells. Only the general locality can be indicated by the geologist or geophysicist, and within it the drill, through one test hole after another, must carry the exploration to completion.

If an active, deliberate search for stratigraphic pools is undertaken by the producing industry, two reversals in recently established trends may be anticipated: (1) the recently manifested decline in the number of dry holes per major discovery will be arrested or reversed; (2) the demand for the services of competent geologists, which has slackened

recently in favor of geophysical exploration, will be quickened. Drilling in search of stratigraphic pools will mean, practically, "core drilling" large areas to extreme depths. "Core-drill" holes are almost invariably dry holes, and to be most useful they must be supervised so closely by geologists as almost literally to be drilled by geologists.

In summary, it may be said: 1. Our discovery rate in oil finding was rather uniformly accelerated as the industry expanded through the period subsequent to the year 1900 until, during the years 1926-1930, it reached a peak more than double our current rate of consumption. Thereafter it declined sharply until it averaged, during the next 5 years, only about 70 per cent of our current rate of consumption. 2. This is true whether discovery rate be measured in terms of barrels of reserves found, or in terms of major oil fields found. 3. Geological exploration has been dominantly our most effective finding method in the past. It has been less effective during the past 10 years than it was previously, and has definitely yielded leadership to geophysics during the last 5 years. 4. Whether the failure of the discovery rate to maintain its earlier pace is to be explained as being an effect of the recent industrial depression, as is generally assumed, or as resulting from the inadequacy of our finding technique to cope with increasing difficulty of oil finding, may be debatable, but the evidence supports the latter as a major contributing factor. 5. We now drill fewer dry holes per major discovery than we did formerly, but this trend may be arrested or reversed in future exploration. 6. Our proved reserves, now about 13 billion barrels, are probably adequate or even excessive, viewed solely as a reserve supply, but they should be maintained at their present level to admit of production in an efficient manner and at the same time at the rate necessary to meet consumption. 7. Our finding technique definitely needs to be strengthened. Merely finding structural traps at greater depths and drilling deeper wells to tap them, as we have been doing in recent years, promises too little to permit us to rely upon it alone. 8. The most hopeful means of improving our oil-finding accomplishment is embodied in Levorsen's suggestion, made a year ago, that we initiate an intensive search for "stratigraphic traps." 9. This enterprise, if adopted, may be expected to cause an increase in the ratio of dry holes to discoveries, and to quicken the demand for expert geological supervision. But it should accomplish its purpose; namely, the discovery of important additional reserves of petroleum.

FUTURE OF PETROLEUM EXPLORATION IN UNITED STATES¹

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ABSTRACT

Prospecting for new sources of supply is a part of the ordinary routine business of the oil industry to an extent not true for any other mineral industry.

The art of prospecting for petroleum has been developed to a high degree of perfection, but it has developed naturally as an outgrowth of the production department. Functionally, no branch of the entire industry is more important than the exploratory branch and it should be established as a department as independent as refining. This is true even in connection with the drilling of exploratory wells.

Some of the advantages which should follow such form of organization are: more effective results as a consequence of the placing of definite responsibility; the development of cost accounting for oil finding; and the development of definite drilling equipment and technique for exploration as distinguished from the existing exploitation technique and equipment.

Prospecting for new deposits is of prime importance to the petroleum industry and is a part of the ordinary routine day-by-day business of that industry to an extent not true in any other type of mining. This condition arises from no fault or virtue inherent in the industry, but rather is a result of the excessive demands of increasing consumption—demands which are really exorbitant in ratio to any reserve which we possess.

It could hardly be otherwise for an industry faced with such demands for its products. Currently, the equivalent of ten to twelve 100-million-barrel pools is required annually to keep proved reserves, which have never been too great, in balance with the annual consumption of 1 billion to 1 billion, 200 million barrels now indicated for the United States alone. We now consume annually more petroleum than was produced during the first half of the duration of the industry. We consume annually more than the equivalent of 5 or 6 Spindletops; 2 or 3 Long Beaches, Cushings, Salt Creeks, Bradfords, or Oklahoma Cities; 1½ Conroes, Yates, or Kettleman Hills; or ⅓ to ¼ of a phenomenal East Texas pool. All of the oil produced in Pennsylvania since the beginning of the industry or all of the oil produced in the Gulf Coastal Plain of Texas and Louisiana, as a result of 35 years of intensive search and development, is sufficient to meet only one year's requirements. The entire past production of California, the banner state, would

¹ Read before the Association at Los Angeles, March 17, 1937.

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meet our national requirements for only 5 or 6 years at the present rate of consumption. In fact, all of the petroleum hitherto produced in the 77-year life of the industry in the United States is sufficient to satisfy our requirements at the present rate of consumption for only 15 to 17 years.

We can estimate with reasonable accuracy the amount of the nation's proved reserves and we can speculate as to the amount of oil yet to be discovered. Reserves generally appear to be low or inadequate and even in the midst of over-production, the individual company is concerned for its own reserves, and the industry as a whole searches actively for the pools which must produce our supplies only a few years hence. We have been prematurely alarmed in the past, or so it now appears, but although we can not prove it, common sense tells us that we can not continue at our present rate of production indefinitely or, in terms of the life of a nation, very far into the future.

That we as a nation should live only for today and willingly and carelessly deplete our petroleum reserves to the point where we may soon be left with only an inadequate and high-cost production and, the greatest consuming group in the world, at the mercy of foreign supply and foreign prices, seems to me to be unthinkable.

Conservation has been sanely defined as wise use. The wise use of our petroleum resources requires that we do several things, among which are:

1. Admit and even welcome foreign oil in so far as it can be done without too great dislocation of our own industry;
2. Encourage American companies to secure foreign reserves;
3. Advance the technique of prospecting for oil;
4. Advance the technique of producing oil;
5. Increase the efficiency of refining processes;
6. Increase the efficiency of our use of motor fuel; and
7. Refrain from the less desirable uses of oil, such as burning it for fuel.

I do not expect agreement with this outline. Parts of it may be impracticable. I do not even propose to discuss it further.

We as geologists are concerned chiefly with the advancement of the techniques of prospecting and production. The petroleum geologist is generally regarded by the industry as well as by his brother geologists as a prospector. It is our particular business and it is, therefore, to the prospecting problem that I address myself.

The oil industry is generally regarded as having commenced with the completion of the Drake well, a well 69½ feet deep and pumping

about 25 barrels daily, completed at Oil Creek, Pennsylvania, on August 29, 1859. As a result of the development which followed, the United States became a supplier of lamp and lubricating oils to the world. Gasoline was of no consequence—a waste by-product. By the end of the century, about 1 billion barrels of oil had been produced.

With the beginning of the present century, fuel oil became important and the automobile came in. During this fuel-oil transition period ending, say, in 1910, we produced another $1\frac{1}{2}$ billion barrels of oil.

During the gasoline or motor-fuel period we have produced approximately 16 billion barrels of oil and are now at an all-time peak of about $3\frac{1}{4}$ million barrels of oil per day.

It was the pressing demand for motor fuel which forced the oil industry to rationalize and develop its prospecting technique.

The historical development of a rational technique of prospecting for petroleum in the United States, the exploration of which is certainly much further advanced than that of any other petroleum-bearing area of major proportion, should be of great interest to the economic geologist as an example of the possibilities of the development of the art of prospecting in a mineral industry, and to the industrialist as indicating trends which may be of great future importance to him.

Petroleum was first discovered accidentally and in quantities great enough to make it a nuisance in wells drilled for brine in Pennsylvania, West Virginia, and Kentucky. It was first discovered purposefully by the Drake well. This first well was drilled near an oil spring by men whose entire knowledge of the occurrence of petroleum could not have been greater than a general recognition of the fact that oil could sometimes be skimmed from the flow of springs and that it was often found in wells drilled for brine.

The second oil strike was made by a blacksmith at Franklin who bought iron on credit, hammered out rough drilling tools on his own anvil, and with the aid of his stalwart son "kicked down" a well to successful completion at a depth of 72 feet near an oil spring on his own farm. It was as easy as that.

Following these discoveries, prospecting by drilling to exceedingly shallow depths was continued by wildcatters—gentlemen adventurers—who were sufficient in numbers and enthusiasm to discover new pools faster than they were required. Their prospecting continued on the basis of direct indications—oil or gas seepages, oil found more or less accidentally, or the occurrence of bitumen-impregnated rocks—until most of the major oil regions of the United States had been found.

Although geologists early recognized the structural occurrence of the petroleum, little was done toward using geology as a prospecting tool until about 1913-1914 when it began to be generally adopted by the industry.

The history of geological prospecting from that time on is largely one of broadening views as to the nature of structures adequate to trap oil so as to form commercial pools and of the exhaustion or near exhaustion of techniques and the development of new techniques for finding such structures.

The first geologic work was largely surface geology for the discovery of structure. Drilling was to shallow depths. Most of the oil-bearing areas were mapped, structures with adequate surface expression were found and explored, and by 1920 there seemed to be but little more to be done by this method.

Subsurface studies have always been important. Carried on at first as a part of the normal geologic survey of any area, and largely on the basis of drillers' logs, by 1917 such studies had begun to be specialized as the work of a definite department. Drillers' logs were poor and efforts to construct more exact logs on the basis of sample examinations were made. By 1925 micro-paleontology began to form the real basis and impetus for subsurface studies, though many areas still rely entirely or almost entirely on lithologic determinations. This subsurface technique, dependent as it is upon the drilling of wells, will probably continue to be the backbone of petroleum geology as long as exploration continues.

In the early 1920's the science of the physicist was brought to the aid of the geologist for the solution of the problem of oil prospecting, and geophysics became important. Its first and greatest successes have been in the finding of additional salt domes in the Gulf Coast area—an area previously amenable only to a type of prospecting hardly more rational than random drilling. With the vigorous and hectic campaigns which followed the successes of these new methods, their use spread until we can now see the possibility of exhaustion or at least of considerably diminished returns from the use of existing techniques.

Geophysics has grown up too much alone for the greatest advancement of its usefulness as a prospecting tool. In the broadest sense, it is the science of earth physics and includes geology among a host of other sciences. As we know it in the petroleum industry, however, it is strictly a geological tool—new implementation for the geologist who, by its use, can secure important and critical geological information not otherwise available to him.

The interpretation of geophysical data in useful terms is ultimately

a problem of geology. The correct solution is generally a question of geological probability and in many cases is so simple and obvious that the need for expert solution is practically nil. The earliest and greatest successes of geophysics—in the search for the so-called shallow salt domes of the Gulf Coastal Plain—were operations of this type. The finding of velocities of 16,000-18,000 feet per second on a time-distance curve from a refraction profile was almost positive evidence of the existence of a salt dome in this region and not to be interpreted otherwise. This unique interpretation was as well known to the geophysicist as to the geologist and a whole congress of geologists could not have improved the interpretation.

Most of the problems which involve geophysics today, however, are much less simple and the writer believes that geologist and geophysicist can agree that future problems are likely to become increasingly complex and to require more and more geological direction as to the placing of points from which information is to be secured and that finally skilled geological interpretation is essential.

The history of prospecting for petroleum in the United States is also largely a question of a series of new techniques—of new methods of attack. Each of these in turn has been used vigorously throughout large areas until its usefulness has been largely exhausted. We began with surface mapping, but by 1920 much of the surface of the known petroliferous areas had been mapped. Core drilling followed until the cream of the core-drill possibilities was gone. Geophysics came in and, failing further advances or the development of new methods, will in turn serve its purpose and become of less importance. Whether some new geophysical method, possibly a direct one, will in turn be developed in order to meet a pressing need of finding the so-called non-structural oil is a matter for speculation. Serious research to such end is under way.

As already intimated, subsurface studies constitute the one continuing technique which will probably continue as long as we have an industry. Even this technique changes, however. We began, using drillers' logs; then determination from samples and cores; then paleontological determinations with the aid of micro-paleontology; now electrical logs. It is perhaps not too much to look into the future and see deep wells drilled for geological information alone. None of these techniques is ever entirely exhausted and most of them overlap, but, except for subsurface studies, most of them reach a marginal and practically exhausted stage.

No consideration of prospecting is even approximately complete which fails to acknowledge the tremendous importance, both as prime

discoverers and as contributory discoverers, of the thousands of wildcat wells drilled casually or at random by individuals, syndicates, etc., without benefit of geologic clergy. Geologists generally have been conservative and it is the venturesome wildcatter who has stepped out and opened up new areas. This is a brilliant example of the effectiveness of multiple effort. The development of the petroleum reserves of the United States has been far more of a result of coöperative effort than we are likely ever to realize.

Notwithstanding its vital importance to the individual enterprise, to the industry, to the nation, and to the world, prospecting has been a function of the producing branch since the earliest days of the industry. Wells were shallow, definite, and probably less expensive than any other type of prospecting could have been in the early days of the industry, even if a technique of prospecting had been developed, which had not, and there were venturesome souls willing and able to drill enough wildcat wells to keep the industry in its characteristic rhythm of over- and under-production.

The trend throughout the 20 years during which prospecting has been emerging from the broader field of production as a separate and definite technique, as well as the necessities of the future, indicates the establishment of prospecting or exploration on a basis almost as distinct from production or exploitation as is refining or marketing.

The exploration department of the future will include geological work (subsurface studies, surface studies, stratigraphy, paleontology, geophysics), scouting, engineering, and land leasing, as it does effectively in many of the best organized companies of today; and it will also include organization for the drilling of exploratory wells. Its business will be strictly that of securing oil reserves, and, for greater effectiveness, it will be relieved of all other duties in so far as possible.

Three definite and outstanding advantages should result from such form of organization. First and foremost should come the development of special equipment and practice for the drilling of exploratory or wildcat wells. Secondly should come the development of cost accounting and statistical control adequate to determine the all-important cost of oil finding. Thirdly, the focusing of attention on exploratory effort and the fixing of responsibility for the degree of success should advance materially the development and application of the technique of prospecting.

Exploratory wells—wildcats—are being drilled with the same type of equipment and by the same practice as wells intended to develop proved fields. Located in unproved ground and often without definite objectives, they are generally more costly than development wells.

Ours is unique among the mineral industries again in that the prospect hole is more costly than the mine.

This condition exists because we have never considered ourselves able to prove the existence of commercially important oil deposits without actually completing a producing well. I suggest, however, that with improved coring, core analysis, electrical logging, casing perforation, stage cementing, drill-stem testing, etc., we have advanced very far in perfecting testing methods and that we should be near the point where we can determine whether or not oil in commercial quantities is present without actually completing a well. Properly supported, engineers should be able to develop a comparatively light and mobile rig for drilling holes adequate only for test purposes quickly and cheaply. It is even conceivable that the future may see wells drilled solely for the purpose of securing electrical logs. If negative results should be secured, in most instances the prospect would be condemned as surely as by a large and expensive hole. If positive, the actual drilling of the discovery producing well and the setting in motion of the long train of consequences which follow discovery—the oft-times enforced development of an oil field—might be postponed to suit the convenience of the prospector.

I believe that students of the problems of prospecting will agree that we are reaching the point where we shall be prospecting in the United States more and more for the so-called stratigraphic rather than the purely structural accumulations and that these pools will require considerably more drilling for discovery than the structural type of pool. Many of the wells will be drilled essentially for geological information—glorified core drilling. This development of prospecting technique will make it even more imperative to develop a technique of prospecting drilling distinct from and much cheaper than existing types of drilling for production.

Second in importance should come the establishment of cost accounting as a control over our prospecting effort and more critical statistical analyses of our successes and failures in prospecting. Above all, we should determine the cost of oil finding—the cost of reducing oil reserves to reasonably knowledgeable possession, constituting one of the most important costs in the entire oil industry.

Company accounts are not set up generally in a form which makes the determination of prospecting costs a problem for easy solution and this is particularly true of the finding costs. Most companies determine an over-all production cost per unit barrel which includes most of the various components of a finding cost, but it is essentially the cost of finding oil to be produced in the future, and, in the normal

production cost per barrel, it is combined with the cost of mining oil largely found in previous years and is arbitrary and inexact. It is of little or no value as a cost control to prospecting effort, although as a practical business matter the production cost per barrel figure is probably better than the more exact and correct cost would be, since it combines the actual mining cost with the current finding or reserve replacement cost.

One of the difficulties in determining finding costs is that accountants have to make assumptions upon which to proceed; they may even have to make more than one set of assumptions and determine their costs within limits rather than as precise figures. Furthermore, the essential estimate of reserves is likely to be only approximate at a time near discovery and to become exact only after the property has been fully developed and has produced for some years. Finding costs will also vary tremendously when calculated for periods of time as short as a single year. I have seen the finding costs for a major company showing those for the worst year to be $27\frac{1}{4}$ times as great as those for the best year.

As to critical analyses of statistics, we do not even have general statistics for the industry as a whole on the results and hazards of prospecting. This is a problem with which the American Petroleum Institute and the Association might well concern themselves.

As geologists, we have been too prone to accept our failures philosophically and to spend too much time in considering the development of our successes. If I might draw upon my own experience in developing a geophysical method, I would recommend that we waste as little time as possible on the successes, but that we restudy critically and seriously the failures. It is the proper method to advance and perfect the technique of prospecting.

I fear that I have not made the desirability and even necessity for cost accounting in prospecting as clear as it might be made. The actual cost of producing oil is the cost of finding—the cost of reducing to knowledgeable possession—of getting title to the oil in ground—plus the cost of mining the same oil. How can you decide whether to buy proved oil or prospect for it if you do not know what the cost of finding is likely to be?

Cost control can even go much further to advantage; e.g., determining the unit cost of finding prospects. It may be that prospects can frequently be bought more cheaply than they can be found. Do we know at present?

All in all, our necessity is for a considered and critical control, cost and statistical, of this normal and essential part of the oil industry.

Again let me say that the establishment of a separate and distinct prospecting or exploratory department should result in the focusing of attention on exploratory effort and the fixing of responsibility for the degree of success, and should result in better and more effective work being done than by any other method. Fixing of responsibility for increasing their company's reserves, and relief from all outside and extraneous duties, even the pleasant one of watching an unimportant well being "brought in" in a developing field, can only result in increasing the effectiveness of a company's prospecting effort.

Finally, the health of any oil company today is dependent on its reserves. This is even true for the industry as a whole. The industry can not deny that it is, to borrow terms from the mathematician, a dependent function of an independent variable—exploration—and exploration is, as I have said before, a part of the ordinary routine of the petroleum industry to an extent not true of any other mineral industry. Proved reserves in terms of annual consumption may be expressed for coal in thousands of years, for iron in hundreds of years, for copper in tens of years, but for oil they are always expressed in years and not too many of them.

Maintaining reserves for a company or for the nation can only be accomplished by increasing the effectiveness of prospecting. Exploration is a highly skilled and highly technical process on averages and likely to become more so in the future. It is my belief that the future of petroleum exploration lies in its organization as a separate department, developing and refining its equipment and technique, and accepting clear responsibility for the success or failure of its efforts.

STRATIGRAPHY OF THE SUNDANCE FORMATION AND RELATED JURASSIC ROCKS IN WYOMING AND THEIR PETROLEUM ASPECTS¹

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ABSTRACT

The Sundance formation of Wyoming contains a stratigraphic break which gives evidence of the result of a period of erosion during Divesian time. The lower portion of the Sundance formation is believed to be equivalent to part of the Twin Creek formation of western Wyoming and to part of the lower Ellis formation of northwestern Wyoming, as it was originally described. The upper portion of the Sundance formation is believed to be in part equivalent to the lower Beckwith of western Wyoming (the Preuss and the Stump formations of southeastern Idaho), and to the upper portion of the original Ellis formation of northwestern Wyoming. Oil production from the Sundance is found in anticlinal structures which lie in a belt slightly more than 100 miles broad trending in a northeast-southwest direction across the eastern portion of Wyoming. This belt is roughly parallel to the shore line of the Logan (Sundance) sea. Theories to account for the distribution are (1) "up-dip" migration before concentration in anticlines, (2) biochemical relationships, and (3) textural differences. Flushing appears to have played an important part in some structures.

INTRODUCTION

Many problems are presented by the marine Jurassic rocks which occur in the state of Wyoming, and the importance of these problems has been amplified in the past two years by the discovery of oil in large quantities within the Sundance formation. The problem of the age of the Jurassic rocks of Wyoming compared with the European type section has always been of scientific interest. The work of Crickmay³ has done much toward a solution; Reeside also has made many contributions toward this end. The problem of correlation between (1) the southeastern Idaho section (the Nugget, the Twin Creek, the Preuss, and the Stump formations), (2) the northwestern Wyoming section (the Ellis formation), and (3) the marine Jurassic which is present over much of the rest of the state of Wyoming (the Sundance formation), is not completely understood. The present work was undertaken primarily in an attempt to shed some light on this problem of correlation.

¹ Manuscript received March 8, 1937. Published by permission of the Geological Survey of Wyoming.

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³ C. H. Crickmay, "Study in the Jurassic of Wyoming," *Bull. Geol. Soc. America*, Vol. 47 (1936), pp. 541-64.

The petroleum aspect of the Sundance formation is briefly dealt with as a supplement to this paper. Included are statistics on production, limitations of known production, and the consideration of theories on the accumulation and distribution of the Sundance oil.

Acknowledgments.—The field work connected with this problem was partially financed by the Geological Survey of Wyoming, and through that agency, completion of the paper was made possible. The

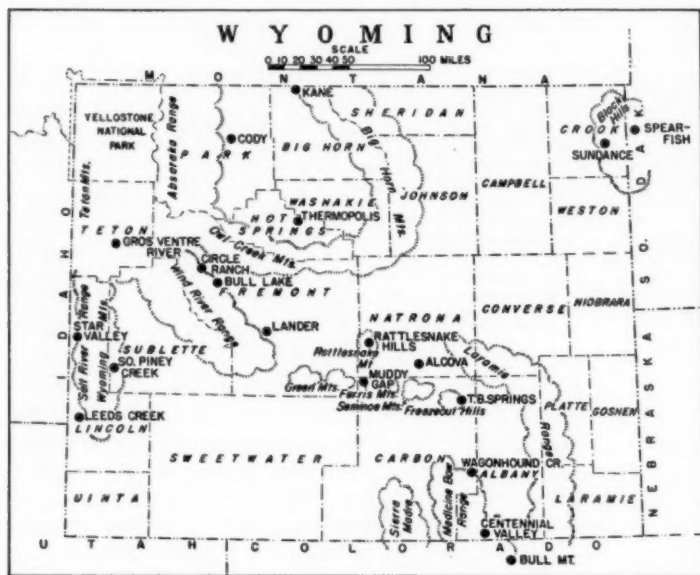


FIG. 1.—Index map.

writer is indebted to the faculty of the Geology Department at the University of Wyoming for valuable aid and suggestions. S. H. Knight made many valuable suggestions; R. H. Beckwith contributed aid and suggestions; H. D. Thomas made a critical review of the manuscript and contributed many valuable suggestions. The writer is greatly indebted to J. B. Reeside, Jr., and W. W. Rubey of the United States Geological Survey, and to G. Marshall Kay of Columbia University for a review of the manuscript and many valuable suggestions. A. M. Morgan furnished a collection of fossils from the Gros Ventre region. Pierre LaFleiche, Wyoming Mineral Supervisor, furnished much valuable information in connection with statistics of petroleum production from the Sundance formation.

PREVIOUS INVESTIGATIONS OF JURASSIC DEPOSITS IN WYOMING

Black Hills.—The presence of Jurassic rocks in the Black Hills (Fig. 1) was first ascertained by Hayden in 1857; he discovered marine Jurassic fossils which were identified and described by Meek. Hayden's descriptions were brief, and he included red beds of Triassic age in the Jurassic. In 1874, N. H. Winchell recorded some facts about the character and distribution of the Jurassic rocks in the same area. Henry Newton,⁴ in 1875, made an extended survey of the Black Hills and devoted a large part of his report to the description of the marine Jurassic rocks. He described a number of exposures in some detail, but made no attempt at classification. The paleontology of the Jurassic rocks was included in Newton's report by R. P. Whitfield,⁵ in which the fossils collected from marine Jurassic rocks of the area were described and illustrated.

N. H. Darton,⁶ in 1899, published a report on the Jurassic formations of the Black Hills region, in which he applied the names Sundance and Unkpapa to the marine Jurassic beds. Darton gave detailed descriptions of several measured sections, and included a faunal list of all of the fossils which had been reported from the area. Darton's original description of the type section of the Sundance formation includes the following statement.

This member of the Jurassic [the Sundance] . . . carried abundant marine fossils. . . . The formation comprises shales and sandstones, in greater part in alternating series which vary somewhat in relation in different portions of the region. The shales are mainly dark green and the sandstones pale buff in color, but there is an intermediate member of sandy shales and sandstones of reddish color, and often a local basal member of red sandstone. The shales usually include thin layers of limestone which are always highly fossiliferous. Fossils also occur in the sandstones.

In describing the Unkpapa Darton says:

This formation is always clearly separable both from the Sundance shales below and the Beulah shales, or Lakota sandstone above. It is massive fine-grained sandstone, varying in color from white to purple or buff. . . . Contacts with the overlying buff sandstone of the Lakota formation are frequently exposed, and they are seen to be marked by considerable unconformity by erosion.

⁴ Henry Newton and W. P. Jenney, "Report on the Geology and Resources of the Black Hills of Dakota," *U. S. Geol. and Geol. Survey Rocky Mountain Region* (Powell) (1880).

⁵ R. P. Whitfield, "Paleontology of the Black Hills of Dakota," *U. S. Geol. and Geol. Survey Rocky Mountain Region* (1880).

⁶ N. H. Darton, "Jurassic Formations of the Black Hills of South Dakota," *Bull. Geol. Soc. America*, Vol. 10 (1899), pp. 383-86.

In 1905, N. H. Darton⁷ described in detail the Sundance formation of the Sundance Quadrangle. He described the very fossiliferous upper shales and included a faunal list from those beds. He also pointed out that "... occasional layers of fossiliferous limestone occur in the lower shales," and reported "*Pentacrinoides asteristicus*" and other commonly occurring forms. He further states:

All of these are of Upper and Middle Jurassic age. The Sundance formation is believed to be equivalent to the Ellis formation of Montana and the Yellowstone Park region.

Central and eastern Wyoming.—Hayden,⁸ in 1870, referred to the Jurassic rocks of central and eastern Wyoming, briefly noting their geographical distribution and fossil content. Other early surveys⁹ reported the presence of rocks of Jurassic age in this area and noted their distribution, lithologic character and fossil content.

W. C. Knight,¹⁰ in 1900, reported on the Jurassic rocks of southeastern Wyoming. He noted the distribution and fauna and made suggestions as to the correlation of these rocks with the European type section, based on reptilian remains. In the same year, W. N. Logan¹¹ published a paper which dealt with the stratigraphy and invertebrate paleontology of the Freezeout Hills area, and in which a rather extensive description of the section was given.

Darton,¹² in 1908, published a paper on the Paleozoic and Mesozoic formations of part of central Wyoming, in which he briefly considered the distribution of the Jurassic rocks and believed them to be equivalent to the Sundance formation of the Black Hills.

J. B. Reeside, Jr.,¹³ described and figured several ammonites collected at various localities from the Sundance over the state of

⁷ N. H. Darton, "Description of the Sundance Quadrangle," *U. S. Geol. Survey Atlas Folio* (1905), p. 3.

⁸ F. V. Hayden, *Geological Survey of Wyoming and Contiguous Territory* (1870).

⁹ G. K. Warren, *Preliminary Report of Explorations in Nebraska Territory and Dakota* (1855-56-57); F. B. Meek and F. V. Hayden, "Paleontology of the Upper Missouri," *Smiths. Contr. Knowl.* 14, Vol. 172, Art. 5 (1865); Clarence King, "Systematic Geology," *40th Parallel Survey* (1878), pp. 286-87; F. V. Hayden, *Geological Survey of the Territories* (1867-69).

¹⁰ W. C. Knight, "Jurassic Rocks of Southeastern Wyoming," *Bull. Geol. Soc. America*, Vol. 11 (1900), pp. 377-88.

¹¹ W. N. Logan, "The Stratigraphy and Invertebrate Faunas of the Jurassic Formations in the Freezeout Hills of Wyoming," *Kansas Univ. Quarterly Bull.*, Vol. 9, No. 2 (April, 1900), pp. 109-34.

¹² N. H. Darton, "Paleozoic and Mesozoic of Central Wyoming," *Bull. Geol. Soc. America*, Vol. 19 (1908), pp. 403-74.

¹³ J. B. Reeside, Jr., "Some American Jurassic Ammonites of the Genera *Quenstedticeras*, *Cardioceras*, and *Amoeboceras*, of the Family *Cardiocerata*," *U. S. Geol. Survey Prof. Paper* 118 (1919), pp. 1-64.

Wyoming. From the distribution of these fossils, Reeside has drawn the conclusion that:

The Sundance formation has been considered by nearly all American authors as a single paleontologic and stratigraphic unit of lower Oxfordian age, in the sense that the term was applied by continental and particularly Russian stratigraphers. The present study bears out this interpretation.

A. E. Brainerd and I. A. Keyte,¹⁴ in a paper published in 1927, reported the finding of a Sundance fauna below a horizon which was at that time included in the Chugwater formation, and suggested a new division of the Jurassic rocks of Wyoming. Brainerd and Keyte state:

The zone at the top of the Chugwater is widespread in the state of Wyoming. . . . It is suggested that this zone . . . be given a new name and placed in the Jurassic. It appears . . . that this would make for simpler stratigraphy than to include these red shales in the typical Sundance, inasmuch as there appears to be a definite break between the two.

The paper thus points out an erosion surface within the Sundance formation.

Willis T. Lee,¹⁵ in correlating the Sundance formation from northwest to southeast across the state of Wyoming, believed that the thinning from northwest to southeast was due to erosion. Lee subdivided the Sundance into four members which are fairly consistent throughout the area in which he worked.

John G. Bartram,¹⁶ in 1930, compiled many sections of Jurassic rocks in the state of Wyoming and constructed cross sections, showing his correlations. He correlated all of the Sundance, except the basal sand, which he referred to the Nugget, with the Twin Creek and lower Beckwith of western Wyoming.

C. H. Crickmay,¹⁷ in 1931, in his noteworthy work on the Jurassic history of North America, considered the marine Jurassic of Wyoming to have been deposited as essentially a single unit and assigned it to the Argovian and the Kimmeridgian of the European type section.

In a later paper, Crickmay¹⁸ again correlated the typical Sundance

¹⁴ A. E. Brainerd and I. A. Keyte, "Some Problems of the Chugwater-Sundance Contact in the Big Horn District of Wyoming," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 11 (1927), pp. 747-52.

¹⁵ Willis T. Lee, "Correlation of the Geologic Formations Between East-Central Colorado, Central Wyoming, and Southern Montana," *U. S. Geol. Survey Prof. Paper* 149 (1927).

¹⁶ John G. Bartram, "Triassic-Jurassic Red Beds of the Rocky Mountain Region," *Jour. Geol.*, Vol. XXXVIII, No. 4 (1930), pp. 335-45 and 667-71.

¹⁷ C. H. Crickmay, "Jurassic History of North America; Its Bearing on the Development of Continental Structure," *Proc. American Philosophical Society*, Vol. LXX, No. 1 (1931), pp. 15-102.

¹⁸ *Idem*, "Study in the Jurassic of Wyoming," *Bull. Geol. Soc. America*, Vol. 47 (1936), pp. 541-64.

with the Argovian and the Kimmeridgian, and considered the Sundance as a single unit. However, the basal sandstone of the sections in eastern Wyoming he thought might be equivalent to the basal Ellis sandstone of Montana, to which he gave a Callovian age.

Yellowstone National Park area.—The name Ellis was given by Arnold Hague¹⁹ to the marine Jurassic rocks of the Yellowstone National Park, the name being derived from Fort Ellis, 50 miles north of the Park. This name is now used for the Jurassic rocks of Montana. His description includes the following statement.

This formation [the Ellis] constitutes a series of fossiliferous beds carrying a Jurassic fauna. The formation consists of two divisions: a lower one, limestone, and an upper one, chiefly sandstone. . . .

No attempt was made to further classify the Ellis formation in the original description.

D. Dale Condit,²⁰ in 1918, in the correlation of the marine Jurassic rocks of Montana, made the following statement.

It is suspected that the Ellis represents only the basal portion of the several thousand feet of Marine Jurassic beds in southeastern Idaho, but corresponds closely with the Sundance formation of Wyoming. . . .

Western Wyoming.—In western Wyoming the nomenclature is more complicated (Table I). In 1876, King²¹ noted the presence of Jurassic rocks in western Wyoming, and referred to them merely as Jurassic. Powell,²² in the same year, subdivided the Jurassic rocks in the Uinta Mountains into the Vermilion Cliff and the White Cliff, which are equivalent to the Nugget as the name is used today, and to some of the Triassic below the Nugget, and the Flaming Gorge, which is equivalent to the Preuss, the Stump, and possibly younger beds. A. C. Veatch,²³ in 1907, applied the names Nugget, Twin Creek, and Beckwith to the Jurassic rocks of southwestern Wyoming. Veatch described the Nugget as follows:

The group of yellow, pink and red sandstones bounded below by the gray fossiliferous limestones of the Thaynes formation and above by the dark

¹⁹ Arnold Hague, "Yellowstone National Park Sheets," *U. S. Geol. Survey Atlas Folio* (1896), p. 5.

²⁰ D. Dale Condit, "Relations of the Late Paleozoic and Early Mesozoic Formations of Southwestern Montana and Adjacent Parts of Wyoming," *U. S. Geol. Survey Prof. Paper 120 F* (1918), p. 114.

²¹ Clarence King, *United States Geological Exploration of the Fortieth Parallel* (1876).

²² J. W. Powell, "Report on the Geology of the Eastern Portion of the Uinta Mountains and a Region of Country Adjacent Thereto," *U. S. Geol. Survey Territories vii* (1876).

²³ A. C. Veatch, "Geography and Geology of a Portion of Southwestern Wyoming," *U. S. Geol. Prof. Paper 56* (1907), pp. 56-58.

colored fossiliferous shales and limestones of the Twin Creek formation has been named the Nugget formation. . . .

This formation Veatch named from Nugget Station on the Oregon Short Line Railroad. Veatch described the Twin Creek as follows:

The fossiliferous marine Jurassic, to which has been given the local name Twin Creek formation from the excellent exposures on that creek . . . here consists for the most part of dark, calcareous shales and thin-bedded shaly limestones, though occasionally showing lighter colored sandstone layers. These are sharply limited above by the thick red beds which mark the base of the Beckwith. . . .

Veatch states that

The Beckwith formation, which directly overlies the Twin Creek, has been so named from its occurrence and extensive development on . . . lands now forming part of the Beckwith Ranch, situated just east of the Beckwith Station

Veatch regarded the Nugget as wholly, or at least in part, Triassic, and the lower part of the Beckwith as Jurassic, on the basis of fossils collected from beds which are herein referred to the Stump formation. He stated that

The lower part of the Beckwith formation is thus clearly Jurassic and the remainder probably contains time equivalents of the Lower Cretaceous and Dakota beds, if these occur in this area.

Gale,²⁴ in 1910, for the area of northwestern Colorado and northeastern Utah, used the names which had been applied in southern Utah, and the names applied by Powell²⁵ in the Uinta Mountains, subdividing the Jurassic rocks into (1) the Vermilion Cliff and (2) the White Cliff (which are equivalent to the Nugget), and (3) the Flaming Gorge (which included the present Preuss, Stump, and Morrison formations).

Mansfield and Roundy,²⁶ in 1916, split the Jurassic rocks of Idaho from the lower part of the Beckwith and gave two new formational names. They applied the name, Preuss, from Preuss Creek, in the southeastern part of the Montpelier Quadrangle in Idaho, to the red sandstones and shales at the base of the Beckwith, and the name, Stump, taken from Stump Creek, in the same general area, to the marine sandstone which overlies the Preuss and contains Jurassic fossils.

²⁴ H. S. Gale, "Coal Fields of Northwestern Colorado and Northeastern Utah," *U. S. Geol. Survey Bull.* 415 (1910), pp. 56-59.

²⁵ *Op. cit.*

²⁶ G. R. Mansfield and P. V. Roundy, "Revision of the Beckwith and Bear River Formations of Southeastern Idaho," *U. S. Geol. Survey Prof. Paper* 98 G (1916), pp. 75-84.

Schultz,²⁷ in 1918, used the name Ankareh for the basal Triassic portion of the Nugget as originally named by Veatch. The name Ankareh had previously been used for equivalent beds by Boutwell²⁸ in the Park City Mining District, Utah. For the Jurassic portion of the Nugget formation of Veatch, Schultz retained the name Nugget. For the remainder of the Jurassic rocks, he used the terms as originally applied by Veatch. In a later paper, 1920, which was a regional report on the area around Rock Springs, Wyoming, Schultz²⁹ employed essentially the same nomenclature.

TABLE I*
EVOLUTION OF NOMENCLATURE FOR JURASSIC ROCKS IN WESTERN WYOMING

| Standard | Clarence King (1876) | Powell (1876) | Veatch (1907) | Gale (1910) | Schultz (1920) | Mansfield (1927) |
|-------------|-------------------------|--------------------|------------------|-----------------|-------------------|---------------------|
| Cretaceous? | | Henry's Fork Group | Bear River | Dakota | Absent | Gannet Group |
| | Dakota | | | Flaming Gorge | | |
| | | Flaming Gorge | Beckwith | | Beckwith | Stump |
| | | White Cliff | Twin Creek | White Cliff | Twin Creek | Twin Creek |
| Jurassic | Jurassic | White Cliff | White Nugget | | | |
| | | Vermilion Cliff | | Vermilion Cliff | Nugget | Nugget |
| Triassic? | Triassic | Shinarump | Red | Shinarump | Ankareh | Wood |

* The nomenclature used in this paper for southwestern Wyoming is that used by Mansfield for southeastern Idaho, *U. S. Geol. Survey Prof. Paper 152* (1927).

In 1927, Mansfield³⁰ discussed the Nugget, the Twin Creek, the Preuss and the Stump formations of southeastern Idaho and included detailed descriptions and a list of the fossils which had been collected from them. He also stated that there is evidence of unconformable relationships between the Nugget and the Twin Creek, and between

²⁷ A. R. Schultz, "A Geological Reconnaissance for Phosphate and Coal in South-eastern Idaho and Western Wyoming," *U. S. Geol. Survey Bull. 680* (1918), pp. 25-26.

²⁸ J. M. Boutwell, "Park City District, Utah," *U. S. Geol. Survey Prof. Paper 77* (1912).

²⁹ A. R. Schultz, "Oil Possibilities in and around Baxter Basin, Wyoming," *U. S. Geol. Survey Bull. 702* (1920), p. 24.

³⁰ G. R. Mansfield, "Geography, Geology and Mineral Resources of Part of South-eastern Idaho," *U. S. Geol. Survey Prof. Paper 152* (1927), pp. 96-101.

the Twin Creek and the Preuss formations, and that the Preuss grades upward into the Stump sandstone.

Baker, Dane, and Reeside,³¹ in 1936, correlated the formations of southeastern Idaho and southwestern Wyoming with those of southern Utah. They correlated the Nugget with the Navajo, the Twin Creek with the Carmel, the Preuss with the Entrada, and the Stump with the Curtis.

GENERAL DISCUSSION OF FORMATIONS

NUGGET FORMATION

GENERAL CHARACTER

The Nugget formation was named by A. C. Veatch³² in 1907 from the locality of Nugget Station on the Oregon Short Line Railroad between the towns of Fossil and Sage, Lincoln County, southwestern Wyoming. There are many good exposures of Nugget sandstone in western Wyoming and they are usually expressed topographically as high rounded hills flanked by steep talus slopes. The talus is typically composed of large angular sandstone blocks many of which are pinkish or light buff in color and weather to dark green or brown. The formation is composed of a sequence of resistant reddish to light buff sandstones and a few interbedded shales. The sand grains are partially rounded, generally small and uniform-sized quartz fragments, bound by a siliceous cement. Bedding planes are prominent and cross bedding is a very common structure.

DISTRIBUTION

The Nugget sandstone is present over much of the western margin of the state of Wyoming and retains a fairly constant lithologic character throughout. In Star Valley (Fig. 1), along the Idaho-Wyoming border, the formation is at least 1,200 feet thick. It thins to the east, and on the South Piney Creek, 20 miles east of Star Valley, measures approximately 1,000 feet. The Nugget is not represented along the northwestern flank of the Wind River Mountains, and it thins out completely at some point between these mountains and the Wyoming Range. At Kelly Slide, on the Gros Ventre River, which is almost due north of the South Piney section, approximately 300 feet of Nugget is present, and at no other sections studied, with exception of those in central Wyoming in the Freezeout Hills area (Fig. 1), is this sandstone

³¹ A. A. Baker, C. H. Dane, and J. B. Reeside, Jr., "Correlation of the Jurassic formations of Parts of Utah, Arizona, New Mexico and Colorado," *U. S. Geol. Survey Prof. Paper 183* (1936).

³² *Op. cit.*, p. 56.

present. In the Freezeout Hills, a sandstone 125 feet thick occurs at the base of the Sundance formation. This sandstone is tentatively correlated with the Nugget because of its lithologic similarity and seeming unconformable relationship to the overlying portion of the Sundance.

AGE AND STRATIGRAPHIC RELATIONS

The relationship of the Nugget formation to older rocks is probably an unconformable one, although no definite evidence of this can be cited at the present time. Mansfield³³ suggests that the relations in some areas indicate an unconformity at the base of this sandstone series. The contact of the formation with younger rocks is unconformable, and this relationship is made evident by an irregular surface in several exposures. It is particularly well demonstrated by the contact on South Piney Creek.

A Jurassic age has been assigned to the Nugget by Mansfield³⁴ on the basis of the stratigraphic breaks which occur between it and the fossiliferous beds of the Triassic Thaynes group.

Baker, Dane, and Reeside³⁵ consider the Nugget equivalent to the Navajo sandstone of southern Utah, to which they give a questionable Jurassic age.

TWIN CREEK FORMATION

GENERAL CHARACTER

A. C. Veatch³⁶ applied the name Twin Creek to this formation, in 1907, from exposures along Twin Creek, between Sage and Fossil, on the Oregon Short Line Railroad. Typical exposures of Twin Creek limestone in western Wyoming form rounded gray hills with steep talus slopes composed of fine chips of gray, shaly limestone. The formation is composed, for the most part, of thin-bedded, fine-grained, black shaly limestone which weathers gray. Massive limestones and sandy limestones are scattered through the entire thickness, and where these are exposed they form ledges. In some localities, a thick shaly sand is present in the upper part, and, locally, lenticular red beds occur near the base. Fossils are far from abundant, but *Pentacrinus* and *Camptonectes* occur commonly in some localities and seem to be distributed throughout most of the formation. In other localities, pelecypods and some very poorly preserved ammonites were collected. The Twin Creek is 2,800 feet thick along the western border of the state.

³³ *Op. cit.*, pp. 96-97.

³⁴ *Ibid.*

³⁵ *Op. cit.*, p. 44.

³⁶ *Op. cit.*, pp. 56-57.

DISTRIBUTION

The distribution of the Twin Creek limestone is much the same as that of the Nugget sandstone. The thickest sections are present along the Wyoming-Idaho and Wyoming-Utah state lines, and the formation thins rapidly toward the east.

TABLE II
STRATIGRAPHIC SECTION OF TWIN CREEK LIMESTONE MEASURED
IN SWIFT CREEK CANYON, 1½ MILES EAST OF APTON, WYOMING

| | Feet | Inches |
|---|-------|--------|
| <i>Preuss red beds</i> | | |
| <i>Twin Creek formation</i> | | |
| Shaly black limestone, mostly covered..... | 435 | 0 |
| Massive sandstone..... | 98 | 6 |
| Very poorly exposed. Thin-bedded shaly black limestone forming rounded hills..... | 458 | 0 |
| Thin-bedded black shaly limestone. <i>Gryphaea</i> sp. was collected from the base..... | 69 | 6 |
| Thin-bedded black shaly limestone..... | 441 | 6 |
| Thin-bedded black shaly limestone weathering gray and forming rounded hills and poor exposures. <i>Dosinia jurassica</i> was collected from the top..... | 342 | 0 |
| Massive to thin-bedded black shaly limestone with a dense massive oölitic limestone at the base 4 feet thick..... | 150 | 0 |
| Covered interval. Talus slope of blocks of limestone weathered from the Twin Creek..... | 80 | 0 |
| Thin-bedded black shaly limestone containing a few massive beds 1-3 feet thick..... | 86 | 0 |
| Thin-bedded black shaly limestone which weathers gray and contains, in the middle, a massive bed about 4 feet thick..... | 54 | 10 |
| Massive and thin-bedded black shaly limestones at the top of which <i>Pleuromya subcompressa</i> was collected..... | 28 | 3 |
| Massive beds, averaging about 1 foot in thickness, of black shaly limestone. Large joints and minor faults are prevalent..... | 44 | 0 |
| Alternating massive and thin-bedded black shaly limestones weathering grayish to brownish. Ammonite ind., <i>Astarte packardii</i> , <i>Pinna</i> sp., <i>Pleuromya</i> sp. were collected..... | 40 | 6 |
| Exposures of thin-bedded black shaly limestone in part covered by a talus slope of small flakes of the same material..... | 95 | 0 |
| Massive black calcareous sandstone which weathers grayish brown.. | 26 | 0 |
| Fine-grained thin-bedded flaky black shaly limestone which weathers gray and forms splintery talus slopes..... | 3 | 3 |
| Massive black bed of limestone which weathers gray..... | 2 | 7 |
| Thin-bedded flaky black shaly limestone which weathers gray and forms flaky talus slopes..... | 13 | 8 |
| Massive hard resistant bed of black crystalline limestone..... | 5 | 0 |
| Extremely thin-bedded flaky black shaly limestone..... | 12 | 0 |
| Hard massive black limestone containing <i>Tancredia</i> sp., <i>Pleuromya</i> sp., and <i>Camptoneustes</i> sp..... | 0 | 10 |
| Soft thin-bedded calcareous shaly sandstone..... | 3 | 5 |
| Massive black nodular to even-bedded shaly unfossiliferous limestone | 26 | 7 |
| Thin-bedded nodular black shaly limestone bed containing poorly preserved fossils. <i>Pleuromya</i> sp. was collected..... | 0 | 6 |
| Massive hard black shaly and sandy limestone which weathers yellowish and forms a prominent hogback. The rock contains many calcite seams and in places appears to be cherty. Distinct joints and small fractures are prominent. No fossils were found..... | 23 | 0 |
| Total..... | 2,539 | 11 |
| <i>Nugget sandstone</i> | | |

Star Valley.—In Star Valley, along the Wyoming-Idaho state line (Fig. 1), the Twin Creek formation is 2,539 feet thick. It is composed for the most part of thin-bedded, fine-grained shaly limestones which characteristically form rounded hills covered with splintery talus. Fossils from this locality are scarce, and when found are poorly preserved. Table II shows a section of the Twin Creek formation measured in Swift Creek Canyon, adjacent to Star Valley.

Leeds Creek.—The section at Leeds Creek (Fig. 1), 15 miles southeast of Cokeville, Wyoming, is about 400 feet thinner than it is in Star Valley. Lithologically, these two sections are very similar, although the faunal content seems to be different in some respects. The presence of *Pentacrinus* in abundance in the Twin Creek limestone on Leeds Creek is in contrast to the Star Valley section. Table III shows a section of the Twin Creek limestone measured on Leeds Creek (Fig. 1).

TABLE III
STATIGRAPHIC SECTION OF TWIN CREEK LIMESTONE MEASURED ON LEEDS CREEK, 15 MILES SOUTHEAST OF COKEVILLE, WYOMING
IN T. 23 N., R. 118 AND 119 W.

| | Feet | Inches |
|---|-------|--------|
| <i>Preuss red beds</i> | | |
| <i>Twin Creek limestone</i> | | |
| Thin-bedded shaly and sandy limestone | 78 | 0 |
| Thin-bedded black shaly limestone which weathers gray with <i>Pentacrinus</i> beds at the top in a ledge-forming, thin-bedded limestone | 190 | 0 |
| Thin-bedded black shaly limestone mostly covered with steep gray flaky talus | 699 | 2 |
| Thin-bedded black shaly limestone, poorly exposed and forming a depression. A 6-inch bed of limestone containing <i>Camplonecles</i> sp. is present at the top | 41 | 0 |
| Thin-bedded black shaly limestone which weathers gray | 119 | 0 |
| Thin-bedded black shaly limestone containing <i>Pentacrinus asteriscus</i> and <i>Camplonecles</i> sp. | 173 | 0 |
| Massive and thin-bedded yellowish calcareous ripple-marked sandstone containing some beds of thin-bedded limestone | 88 | 0 |
| Thin-bedded black shaly limestone carrying fragments of poorly preserved pelecypods. <i>Ostrea</i> sp., and <i>Camplonecles</i> sp., were collected at the top. The upper beds are more massive and black | 204 | 0 |
| Poorly exposed thin-bedded shaly limestone | 10 | 6 |
| Poorly exposed thin-bedded black shaly limestone weathering gray and forming rounded hills | 68 | 0 |
| Red beds. Poorly exposed | 44 | 0 |
| Black thin-bedded to massive sandy and shaly limestones weathering gray to brown and forming a ledge | 88 | 0 |
| Red sandstones and red shales | 110 | 0 |
| Basal resistant shaly limestone containing ripple marks | 224 | 0 |
| Total | 2,136 | 8 |
| <i>Nugget sandstone</i> | | |

South Piney Creek.—On South Piney Creek (Fig. 1), which is approximately 20 miles east of Star Valley, the Twin Creek limestone

is only 928 feet thick. At this locality the Twin Creek is characterized by some massive fossiliferous limestones near the middle of the section, and, in general, the beds are much more fossiliferous than in the exposures which occur farther west. Table IV shows a section of the Nugget, the Twin Creek, the Preuss, and the Stump formations measured on South Piney Creek.

TABLE IV

STATIGRAPHIC SECTION OF NUGGET, TWIN CREEK, PREUSS, AND STUMP FORMATIONS
MEASURED IN T. 34 N., R. 114 W., ON SOUTH PINEY CREEK, 24 MILES
WEST OF BIG PINEY, WYOMING, AND 2 MILES EAST OF
SNYDER BASIN RANGER STATION

| | Feet | Inches |
|--|------|--------|
| <i>Stump sandstone</i> | | |
| The Stump in this locality is not well exposed. It is composed of white to buff to reddish even-grained sandstone. Red beds lie directly above and the Preuss directly below it. The sandstone is cross-laminated in places. | 150 | 0 |
| <i>Preuss red beds</i> | | |
| These beds were not measured, but they appear to be less than 500 feet thick, and form a depression where they are exposed. They are composed, for the most part, of unfossiliferous red shales and sandstones. | 500± | 0 |
| <i>Twin Creek limestone</i> | | |
| Massive greenish black to gray fine-grained arenaceous limestones containing clay galls. | 94 | 0 |
| Gentle slope covered with talus, probably thin-bedded shale or sandy limestone. <i>Pentacrinus asteriscus</i> was collected from the talus. | 48 | 0 |
| Massive black limestone weathering gray and forming ledges. | 8 | 0 |
| Gentle slopes covered with talus. A few thin-bedded shaly limestone beds are exposed containing poorly preserved fragments of fossils. . | 52 | 0 |
| Massive black limestone forming a prominent ledge. The bed contains numerous calcite seams. | 5 | 0 |
| Thin-bedded gray shaly and sandy limestone bed containing <i>Pentacrinus asteriscus</i> | 40 | 0 |
| Massive black ripple-marked limestone beds forming ledges. | 2 | 0 |
| Mostly covered. Thin-bedded shaly and sandy limestone containing <i>Camptonectes</i> sp., <i>Ostrea</i> sp., and <i>Pentacrinus asteriscus</i> | 62 | 0 |
| Light-colored soft sandy shale forming a depression. Near the top is a fossiliferous limestone containing <i>Gryphaea</i> sp., <i>Ostrea</i> sp., <i>Camptonectes</i> sp., and <i>Lima occidentalis</i> | 26 | 0 |
| Massive bed of limestone composed almost entirely of fossils. This bed contains <i>Pentacrinus asteriscus</i> , <i>Lima occidentalis</i> , <i>Parapecten</i> sp., <i>Camptonectes</i> sp., and <i>Ostrea</i> sp. | 2 | 0 |
| Covered interval. The cover contains <i>Camptonectes</i> sp. There are two limestone beds 1 foot thick exposed near the middle. | 142 | 0 |
| Covered interval. A 6-inch bed of very fossiliferous limestone containing <i>Ostrea</i> sp. occurs near the top. | 52 | 0 |
| Massive black limestone at the top 2 feet thick containing poorly preserved <i>Camptonectes</i> sp. Thin-bedded calcareous shale is present in the middle, and massive black limestone at the bottom. The sequence forms a ledge. | 13 | 6 |
| Black shaly limestone with a massive sandy ledge-forming limestone near the base. | 15 | 0 |
| Calcareous and arenaceous soft thin-bedded gray shale containing fragments of fossils. <i>Pentacrinus asteriscus</i> is present in abundance. . | 9 | 0 |
| Massive black sandy ledge-forming limestone full of minute fragments of fossils. <i>Camptonectes stygius</i> and <i>Pentacrinus asteriscus</i> are nu- | | |

TABLE IV (Continued)

| | Feet | Inches |
|---|-------|--------|
| merous..... | 8 | 0 |
| Dark gray calcareous shales weathering buff to brown. Forms a gentle slope..... | 6 | 0 |
| Alternating massive black fossiliferous limestones and thin-bedded calcareous shales. The limestone is oolitic in some places and contains <i>Camptonecles</i> sp..... | 12 | 0 |
| Soft thin-bedded black shales with yellow sandy shales at the base. Forms a gentle slope..... | 8 | 0 |
| Thin-bedded black limestone containing a massive limestone 1½ feet thick at the base..... | 12 | 0 |
| Alternating thin-bedded calcareous shales and massive black limestones. The beds are sandy..... | 13 | 0 |
| Covered interval. Forms a depression in which the soil shows a reddish tinge, probably from lower beds. Contains an 8-inch massive limestone at the base..... | 25 | 0 |
| Mostly covered, with occasional thin-bedded black shaly limestone exposures. Forms a typical splintery, gray talus slope..... | 98 | 0 |
| Mostly covered, with yellowish talus at the base. Here and there thin-bedded limestones are exposed..... | 75 | 0 |
| Red beds. Soft red shale forming a depression..... | 61 | 0 |
| Massive gray knotty and gnarled limestone weathering yellowish and forming a ledge. This bed is very uneven, fragmented, and full of clay galls and mottled shales. It rests on an even-bedded, even-grained, ripple-marked sandstone containing beds of shale at the top of the Nugget. The contact appears to be unconformable..... | 39 | 0 |
| Total..... | 927 | 6 |
| <i>Nugget sandstone</i> | | |
| The Nugget sandstone is not well exposed because of structural complications. However, it appears to be thick—probably more than 1,000 feet..... | 1000± | |

Gros Ventre River.—On the Gros Ventre River (Fig. 1), the Twin Creek is represented by 212 feet of limestones and shales which are extremely fossiliferous. However, the preservation of the fossils is poor. These beds are equivalent to the beds referred to the Ellis formation by Crickmay,³⁷ and to those designated as the lower series of the Ellis formation as originally described.³⁸ The evidence of this relationship is discussed later in the paper. Table V shows a section of the Twin Creek formation measured on the Gros Ventre River, near Kelly Slide (Fig. 1).

AGE AND STRATIGRAPHIC RELATIONS

The Twin Creek limestone is separated from the underlying Nugget formation by an irregular surface which is believed to represent an unconformity, and also bears an unconformable relationship to the overlying Preuss formation as evidenced by a sharp and distinctive change in lithology. Mansfield³⁹ assigns an Upper Jurassic age

³⁷ *Op. cit.*, pp. 541–64.

³⁸ Arnold Hague, *op. cit.*, p. 5.

³⁹ *Op. cit.*, pp. 97–98.

TABLE V

STRATIGRAPHIC SECTION OF SUNDANCE AND TWIN CREEK FORMATIONS MEASURED ON GROS VENTRE RIVER, 2 MILES EAST OF KELLY SLIDE, TETON COUNTY, WYOMING

| | Feet | Inches |
|--|------|--------|
| <i>Morrison?</i> formation | | |
| <i>Sundance</i> formation | | |
| Sandstones and shales of the typical Sundance lithology..... | 423 | 0 |
| Greenish gray shales, sandy in the upper 200 feet. <i>Gryphaea calceola</i> var. <i>nebrascensis</i> occurs in the lower 150 feet. These beds also contain brachiopods and <i>Ostrea</i> sp..... | 302 | 0 |
| Total..... | 725 | 0 |
| <i>Twin Creek</i> formation | | |
| Dark gray fossiliferous limestones from which were collected two specimens of poorly preserved ammonites, <i>Trigonia quadrangularis</i> , <i>Trigonia americana</i> , <i>Trigonia montanaensis</i> , <i>Pleuromya autolytus</i> , <i>Pleuromya subcompressa</i> , <i>Astarte packardii</i> , <i>Gervillia</i> cf. <i>G. montanaensis</i> , <i>Trigonia</i> sp., <i>Ostrea</i> sp., and several small specimens of gastropods..... | 18 | 0 |
| Greenish gray and red shales..... | 65 | 0 |
| Dark shale with bands of limestone; fossiliferous limestone in the base from which the following fossils were collected: <i>Camptonectes platessiformis</i> , <i>Ostrea strigilecula</i> , <i>Ostrea</i> sp., <i>Pleuromya subcompressa</i> , <i>Pleuromya</i> sp., <i>Gryphaea</i> sp., <i>Astarte?</i> sp., <i>Pleuromya</i> cf. <i>P. subcompressa</i> , <i>Trigonia</i> cf. <i>T. quadrangularis</i> | 67 | 0 |
| Dark gray and buff limestones from which were collected the following fossils: <i>Gervillia montanaensis</i> , <i>Trigonia americana</i> , <i>Camptonectes</i> cf. <i>C. extenuatus</i> , <i>Dosinia jurassica</i> , <i>Pholadomya kingii</i> , <i>Astarte packardii</i> , <i>Trigonia montanaensis</i> , <i>Pleuromya subcompressa</i> , <i>Ostrea</i> sp., <i>Trigonia</i> sp., <i>Gryphaea planoconvexa</i> , <i>Camptonectes</i> cf. <i>C. platessiformis</i> , several specimens of small gastropods and 6 specimens of poorly preserved ammonites..... | 62 | 0 |
| Total..... | 212 | 0 |
| <i>Nugget</i> formation..... | 300± | |

to the upper part of the formation and states that the lower part possibly includes Middle Jurassic rocks. Baker, Dane, and Reeside⁴⁰ consider the Twin Creek equivalent to the Carmel formation of southern Utah. Reeside⁴¹ places the Carmel formation in the early Late Jurassic (Callovian) and is of the opinion that the Twin Creek is of the same age.

PREUSS FORMATION

GENERAL CHARACTER

The name Preuss was applied to the red sandstones and shales in the base of the Beckwith by Mansfield and Roundy⁴² in 1916, and the type locality was designated as Preuss Creek, in the southeastern part of the Montpelier Quadrangle, Idaho. The Preuss is composed of unfossiliferous, fine-grained red sands and shales. The topographic

⁴⁰ *Op. cit.*, p. 45.⁴¹ J. B. Reeside, Jr., personal communication (1937).⁴² *Op. cit.* p. 81.

expression of exposure is usually a depression covered with dull red soil, and good exposures are rare. The thickness varies from approximately 1,000 feet along the Idaho-Wyoming state line to 0 feet 50 or 75 miles farther east.

DISTRIBUTION

The Preuss formation is present in a limited area in the west-central and southwestern parts of Wyoming. The thickness is greatest in Star Valley (Fig. 1) and along the southern half of the western border of the state. The Preuss formation thins very rapidly toward the east, and is present only in the sections measured on Leeds Creek, in Star Valley, and on South Piney Creek (Fig. 1). The formation is entirely missing on the Gros Ventre River. In Star Valley, the Preuss has a thickness of over 1,000 feet. It thins to less than 500 feet on South Piney Creek (Table IV), and is not present in any of the exposures which occur east of that locality.

AGE AND STRATIGRAPHIC RELATIONS

The Preuss formation lies between two fossiliferous formations which contain Upper Jurassic fossils, and for that reason has been assigned an Upper Jurassic age by Mansfield.⁴³ The lower contact of the Preuss is marked by an unconformity where it rests on the Twin Creek as indicated by a sharp change in lithology with unfossiliferous red beds lying directly on fossiliferous marine limestones. The Preuss grades into the overlying Stump sandstone. Baker, Dane, and Reeside⁴⁴ consider the Preuss equivalent, in part at least, to the Entrada formation of southern Utah.

STUMP FORMATION

GENERAL CHARACTER

The name Stump was applied by Mansfield and Roundy⁴⁵ in 1916. The name was taken from Stump Peak at the head of Stump Creek, in the Freedom Quadrangle, Idaho, where this sandstone forms the most prominent topographic point. The formation consists mainly of thin-bedded, fine-grained gray sandstones which weather greenish and form prominent ridges where exposed. Near the base is a fossiliferous calcareous sandstone from which Mansfield⁴⁶ reports fossils which occur commonly in the Sundance formation of central and eastern Wyoming. The thickness of the Stump in the western part

⁴³ *Op. cit.*, pp. 98-99.

⁴⁴ *Op. cit.*, p. 46.

⁴⁵ *Op. cit.*, pp. 81-82.

⁴⁶ *Op. cit.*, pp. 99-101.

of Wyoming varies from 250 to 400 feet and it does not appear to deviate greatly from this wherever the formation can be recognized.

DISTRIBUTION

The Stump formation can be recognized as such only in exposures where the Preuss red beds are present. The Stump is about 400 feet thick in Star Valley, and thins to 150 feet on South Piney Creek (Table IV). The Stump is present on Leeds Creek but could not be recognized on the Gros Ventre River.

AGE AND STRATIGRAPHIC RELATIONS

The Stump grades downward into the underlying Preuss red beds and is overlain unconformably by the Gannet group as indicated by massive conglomerates in the base of the Gannet. Mansfield⁴⁷ assigns an Upper Jurassic age to the Stump on the basis of the fauna. Baker, Dane, and Reeside⁴⁸ state that the Stump is equivalent to the Curtis of southern Utah and believe that the Stump is also equivalent to the Sundance formation of central and eastern Wyoming.

ELLIS FORMATION

GENERAL CHARACTER

The name Ellis was applied to the marine Jurassic rocks of the Yellowstone National Park region by Arnold Hague⁴⁹ in 1896, and has since been carried north into Montana. The name was derived from the old military post, Fort Ellis, near Bozeman, in the Gallatin Valley, Montana. The formation as originally described is composed of two divisions, the upper one being sandstones and sandy shales, and the lower one, shales and limestones. The formation contains Upper Jurassic fossils. The thickness of the Ellis varies from 200 to 400 feet or more in the area of the type section.

DISTRIBUTION

The name Ellis is applicable to the marine Jurassic rocks of the Yellowstone National Park area, and northward and westward into the state of Montana. The formation thickens toward the northwest and thins toward the east and southeast.

AGE AND STRATIGRAPHIC RELATIONS

There is an unconformity both at the base and the top of the Ellis formation. The unconformity at the base of the Ellis is necessary to

⁴⁷ *Ibid.*

⁴⁸ *Op. cit.*, p. 8 and pp. 46-47.

⁴⁹ *Op. cit.*, p. 5.

account for Lower and Middle Jurassic and the unconformity at the top is made evident only by a change from marine to continental sediments. Condit⁵⁰ states that the Ellis probably represents only the basal portion of the several thousand feet of marine Jurassic rocks in southeastern Idaho, but corresponds closely with the Sundance formation of Wyoming. However, Reeside⁵¹ states that all of the Ellis fossils known to him are earlier late Jurassic and certainly most of them do not occur in the Sundance. In dealing with the Ellis of the Yellowstone National Park Region, Crickmay⁵² has referred the upper sandy portion, as it was originally defined, to the Sundance, and carried the name Sundance into this area. He assigns these beds to the Argovian and Kimmeridgian of the Upper Jurassic of the European type. For the lower portion of the Jurassic rocks, or the limestone and shale sequence, he retains the name Ellis, and assigns this to the Callovian of the European Upper Jurassic. These divisions and correlations were made on the basis of paleontological evidence.

SUNDANCE FORMATION

GENERAL CHARACTER

Darton⁵³ applied the name Sundance to the fossiliferous marine Jurassic rocks of the Black Hills region in 1899. In general, the Sundance formation is composed of a basal sandstone which contains fossils in a few localities, a series of red shales and sands which are lenticular and generally unfossiliferous, a series of fossiliferous dark marine shales containing some beds of limestone, and an upper sandy series. Many fossils have been collected and described from the dark shales and upper sands. The thickness varies from 0 feet in the southeastern corner of the state to more than 500 feet in the northwestern portion of the state. The average thickness is about 300 feet. In some localities the red beds are not present, and the sandstones vary greatly in thickness and character from place to place. For convenience, in this paper, the Sundance has been divided into an upper and a lower part, the reasons for which are given on pages 758-759, based on evidence of an unconformity.

DISTRIBUTION

The Sundance formation, as recognized in this paper, is present everywhere in the state of Wyoming with the exception of the extreme

⁵⁰ *Op. cit.*, p. 114.

⁵¹ John B. Reeside, Jr., personal communication (1937).

⁵² *Op. cit.*, pp. 541-64.

⁵³ N. H. Darton, "Jurassic Formations of the Black Hills of South Dakota," *Bull. Geol. Soc. America*, Vol. 10 (1899), pp. 383-86.

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TABLE VI

STRATIGRAPHIC SECTION OF SUNDANCE FORMATION MEASURED BELOW THE FORKS OF WIND RIVER ON THE NORTH SIDE OF THE RIVER IN SEC. 3, T. 5 N., R. 5 W., OF THE WIND RIVER MERIDIAN, WYOMING, 12 MILES EAST OF DUBOIS, NEAR CIRCLE RANCH

| Morrison variegated shales | Feet | Inches |
|--|------|--------|
| Sundance formation | | |
| Upper Sundance | | |
| Thin-bedded and cross-laminated friable fine-grained green sandstone containing ripple marks, extremely cross-laminated in places. The beds weather to a pinkish cast and form ledges in this outcrop. | 16 | 0 |
| Alternating resistant gray sandstones 1 inch thick with greenish black shale bands about 1 foot thick containing carbonaceous matter. Typical soft greenish flaky shale. <i>Belemnites densus</i> * (sparse) and <i>Ostrea</i> sp. were collected in talus from this shale; and <i>Kallirhynchia myrina</i> collected from the base. | 15 | 6 |
| A bed of alternating fairly resistant gray to greenish friable sand containing clay galls and dark to greenish shales. The bed contains a 4-inch band of calcareous fossiliferous sandstone 5 feet 6 inches above the base. | 26 | 6 |
| Very fossiliferous resistant sandstone bed about 6 inches thick at the top of this measurement which contains <i>Kallirhynchia myrina</i> , <i>Trapezium</i> sp., <i>Camptonectes</i> sp., <i>C. extenuatus</i> and <i>Gervillia recta</i> in abundance. Below this is a green friable sandstone from which <i>Belemnites</i> was collected. A 6-inch bed of fossiliferous limestone is present at the base and contains <i>Belemnites densus</i> , <i>Gervillia recta</i> , <i>Mytilus whitei</i> ? <i>Kallirhynchia myrina</i> , " <i>Myacites</i> " <i>subellipticus</i> ? and <i>Camptonectes extenuatus</i> ? | 17 | 8 |
| Covered interval, talus containing <i>Belemnites densus</i> | 33 | 0 |
| Fossiliferous chert conglomerate containing <i>Belemnites densus</i> and <i>Camptonectes</i> sp. | 1 | 0 |
| Covered interval, talus containing <i>Belemnites densus</i> , <i>Camptonectes</i> sp., and an occasional small <i>Gryphaea</i> sp. | 30 | 0 |
| White to buff fine-grained thin-bedded sandstone containing ripple marks in the upper part and grading into a shale in the lower part. Contains an occasional <i>Gryphaea</i> sp. | 8 | 0 |
| Soft green shales forming a talus slope with abundant <i>Gryphaea calceola</i> var. <i>nebrascensis</i> | 68 | 0 |
| Covered interval, some <i>Gryphaea</i> and <i>Belemnites</i> found in the talus. A limestone bed is present about 5 feet above the base. | 76 | 0 |
| | 291 | 8 |
| Erosion surface indicated by a sharp change in lithology. | | |
| Lower Sundance | | |
| Hard pinkish to gray massive cherty unfossiliferous limestone 3 feet thick is present at the top. The lower portion is composed of soft gray shale. | 19 | 0 |
| Massive gray limestone containing <i>Camptonectes</i> sp. | 5 | 6 |
| Fossiliferous white to light gray shaly limestone containing <i>Dosinia jurassica</i> , <i>Trigonia quadrangularis</i> , <i>Tancredia inornata</i> , and <i>Tancredia</i> sp. | 6 | 0 |
| Covered interval. Red beds and possibly other beds. | 37 | 0 |
| Covered slope. | 27 | 0 |
| Mottled rocks composed of shales and marls. | 11 | 6 |
| | 106 | 0 |
| Total. | 397 | 8 |
| Red Triassic? beds | | |

* The name *Belemnites* is used in this paper to refer to the same fossil which Crickmay has referred to *Pachyteuthis*. (C. H. Crickmay, "Study in the Jurassic of Wyoming," *Bull. Geol. Soc. America*, Vol. 47 (1936), p. 555.)

TABLE VII

STRATIGRAPHIC SECTION OF SUNDANCE FORMATION MEASURED ON THE
WEST SIDE OF BULL LAKE, IN THE WIND RIVER MOUNTAINS, IN
SEC. 31, T. 3 N., R. 3 W., OF THE WIND RIVER MERIDIAN

| | | Feet | Inches |
|---|--|------|--------|
| <i>Morrison variegated shales</i> | | | |
| <i>Sundance formation</i> | | | |
| Upper Sundance | | | |
| Soft friable thin-bedded yellow sandstone. Fossils were collected from the talus made up of this rock. | | 3 | 0 |
| Very fossiliferous yellow to buff resistant beds forming a ledge near the top of the section. This bed contains <i>Camptonectes</i> sp., <i>Pleuromya</i> sp., <i>Trapezium</i> sp., and <i>Kallirhyncha myrina</i> . | | 5 | 0 |
| Soft yellow friable sandy shale containing clay galls and many gypsum-filled cracks, alternating with beds of unfossiliferous resistant sandstone. | | 20 | 0 |
| Two thin fossiliferous beds containing <i>Camptonectes</i> sp., <i>Kallirhyncha myrina</i> , and <i>Ostrea</i> sp. | | 1 | 0 |
| Hard massive brown chert conglomerate forming a ledge and containing <i>Ostrea</i> sp. | | 2 | 0 |
| Soft unfossiliferous sandy gray shale grading into a dark shaly limestone near the base. | | 24 | 0 |
| Clay and shale beds containing <i>Camptonectes</i> sp. in abundance, and <i>Kallirhyncha myrina</i> , <i>Belemnites densus</i> , <i>Pleuromya newtoni</i> , <i>Volsella</i> sp., and <i>Ostrea</i> sp. | | 1 | 0 |
| Unfossiliferous sandstone. | | 1 | 0 |
| Very thin clay beds containing <i>Camptonectes bellistriatus</i> in abundance and some <i>Belemnites densus</i> . | | 0 | 3 |
| Soft sandy gray shale. | | 5 | 3 |
| Soft sandy shale containing <i>Belemnites densus</i> , <i>Camptonectes</i> sp. and <i>Ostrea</i> sp. | | 22 | 0 |
| Talus slope. One-foot bed of fossiliferous brown chert conglomerate at the base containing <i>Belemnites densus</i> and <i>Pleuromya</i> sp. | | 19 | 0 |
| Interval covered by talus. Unfossiliferous soft gray sand at the base. <i>Pleuromya newtoni</i> , <i>Pleuromya</i> sp., and <i>Camptonectes</i> sp. were collected from the talus. | | 24 | 0 |
| Partially covered. Soft fine-grained white sandstone containing ripple marks is present at the base. | | 26 | 0 |
| Soft shale, mostly covered. | | 40 | 0 |
| Unfossiliferous shale. | | 2 | 0 |
| Soft gray shale containing an abundance of <i>Gryphaea calceola</i> var. <i>nebrascensis</i> and some gypsum. | | 36 | 0 |
| | | 231 | 6 |
| Erosion surface evidenced by sharp change in lithology | | | |
| Lower Sundance | | | |
| Massive pink cherty sandy limestone forming a ledge 3 feet thick, underlain by softer gray sandstone. | | 31 | 0 |
| Gray limestone at the top. Massive ledges formed by middle beds of friable gray sandstone. Massive gray sandstone containing scattered pebbles is present at the base. | | 20 | 0 |
| Six-foot bed of hard white sandstone at the top of soft red sandy shale. | | 15 | 0 |
| Thin-bedded hard resistant shaly limestone which forms a ledge and contains crinkled laminations. The contact at the base appears to be irregular. | | 9 | 0 |
| | | 75 | 0 |
| Total. | | 306 | 6 |
| <i>Chugwater formation</i> | | | |

southeast corner and the area in which the Nugget, the Twin Creek, the Preuss, and the Stump occur. The formation thins toward the southeast and thickens toward the northwest over the state. Extremely good exposures are present along the northeast flank of the Wind River Mountains and in certain localities in the Big Horn Basin area. Also, good exposures are present in central Wyoming, southeastern Wyoming, and the northeastern part of the state.

Wind River Mountains-Circle Ranch.—At Circle Ranch (Fig. 1), one of the northernmost exposures along the northeastern flank of the Wind River Mountains, 401 feet of Sundance are present. Table VI shows a section measured at that locality.

Wind River Mountains-Bull Lake.—At Bull Lake (Fig. 1), which is about 25 miles southeast of the Circle Ranch section, the Sundance is 94 feet thinner than at Circle Ranch. Table VII shows a section measured on the west side of Bull Lake in the Wind River Mountains.

Wind River Mountains-Lander.—The section of Sundance measured near the town of Lander (Fig. 1) contains 255 feet of sandstones and shales, having thinned about 50 feet in the 40 miles between this locality and Bull Lake. Table VIII shows a section measured near the town of Lander.

TABLE VIII
STRATIGRAPHIC SECTION OF SUNDANCE FORMATION MEASURED $8\frac{1}{2}$ MILES
SOUTHEAST OF LANDER, WYOMING, IN SEC. 14, T. 32 N., R. 99 W.

| | Feet | Inches |
|--|------|--------|
| <i>Morrison formation</i> | | |
| <i>Sundance formation</i> | | |
| Upper Sundance | | |
| White cross-laminated friable sandstone forming a ridge | 30 | 0 |
| Soft gray sandy shales forming a depression | 20 | 0 |
| Resistant sandstone bed containing an abundance of <i>Camptonectes</i> sp. . . | 8 | 0 |
| Soft gray shales forming a depression. The upper half of the shale series contains <i>Belemnites densus</i> in abundance. No fossils were observed in the lower half | 150 | 0 |
| | 208 | 0 |
| Erosion surface evidenced by sharp change in lithology. | | |
| Lower Sundance | | |
| Hard massive buff to white sandy and cherty bed | 12 | 0 |
| Alternating red beds, white to purple marls, and marly thin limes. . . . | 35 | 0 |
| | 47 | 0 |
| Total | 255 | 0 |
| <i>Red Triassic? beds</i> | | |

Correlation between the Circle Ranch, Bull Lake, and Lander sections.—Fossiliferous beds in the upper part of the section measured at Circle Ranch (Figs. 1 and 2) are missing in the Bull Lake and Lander sections. These beds contain *Ostrea*, *Belemnites* and *Kalli-*

rhynchia. Another group of fossiliferous beds which are here designated the *Trapezium* beds (Fig. 2), because they are characterized by the fossil *Trapezium*, are present 60 feet below the top of the section at Circle Ranch, a few feet below the top of the Bull Lake section, and are not represented in the Lander section. A series of fossiliferous shales below this, which is here designated the *Belemnites* zone⁵⁴ because of the very abundant occurrence of *Belemnites densus*, is continuous throughout this entire area, being present at all three of the localities. There is evidence of disconformity below the *Belemnites* zone, as indicated by the presence of conglomerates composed of well rounded chert pebbles, reworked belemnites, and in other sections at the same horizon, the presence of well rounded, worn fragments of *Cardioceras* sp. The chert pebbles, when examined in thin-section, have a very distinctive internal structure which is peculiar to the type of secondary chert which occurs as seams in the Sundance east of these localities. A sand is present below the *Belemnites* zone at Circle Ranch and Bull Lake, and this sandstone contains ripple marks, which indicate shallow-water conditions. The fossil zone which is characterized by an abundance of *Gryphaea calceola* var. *nebrascensis*, and is here referred to as the *Gryphaea* zone, wedges out toward the southeast. It is present in the Circle Ranch and Bull Lake sections and absent in the Lander section. This thinning may be partially due to the overlap of the sea in which the upper Sundance was deposited (the Logan sea), and it may be due in part to erosion. It is believed, however, that the erosion which took place above this zone was of a submarine character, and that it does not represent a complete withdrawal of the sea from this area, but merely shallow-water conditions.

There is a sharp break at the base of the dark fossiliferous marine shales in all three of the sections, and this break is present also in other localities within the state, where dark marine shales rest on red sandstones, red shales, and red marls. This break represents an erosional period of some magnitude, and a complete retreat of the sea. Near the base of the section at Circle Ranch, in the top of the red beds, fossiliferous sandstones are present from which were collected *Trigonia quadrangularis* and other fossils, and to these sandstones the name *Trigonia* beds has been applied (Fig. 2). The *Trigonia* beds are not present at Bull Lake or Lander, but wedge out toward the southeast, probably due to overlap.

⁵⁴ The name *Belemnites* is used in this paper to refer to the same fossil which has been referred to *Pachyteuthis* by Crickmay. (C. H. Crickmay, "Study in the Jurassic of Wyoming," *Bull. Geol. Soc. America*, Vol. 47 (1936), p. 555.)

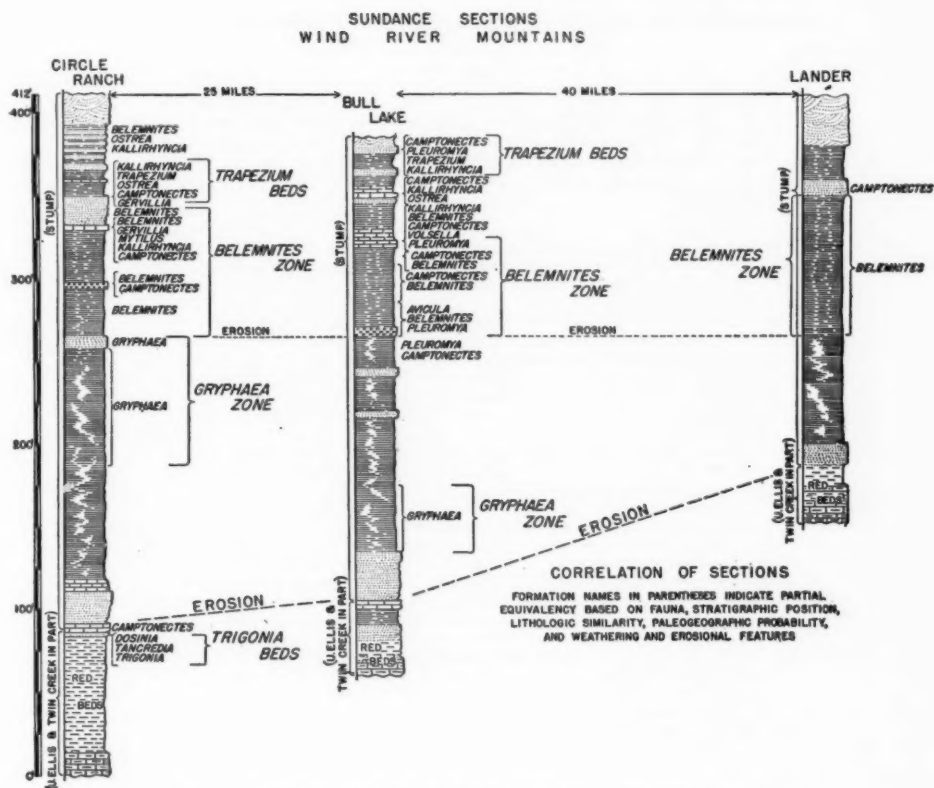


FIG. 2.—Correlation of the Circle Ranch, Bull Lake and Lander sections.

Big Horn Basin-Cody.—A section of the Sundance formation measured near the town of Cody (Fig. 1) is 472 feet thick. The formation at this locality contains a series of red beds and gypsum near the base of the section. Below the red beds and gypsum are sandstones and shales which contain *Camptonectes* sp., and *Ostrea* sp. The section measured near the town of Cody is shown in Table IX.

TABLE IX
STRATIGRAPHIC SECTION OF SUNDANCE FORMATION MEASURED BELOW THE
CANYON OF THE SHOSHONE RIVER, ABOUT 2 MILES WEST OF
CODY, WYOMING, IN SEC. 36, T. 53 N., R. 102 W.

| | Feet | Inches |
|--|------|--------|
| <i>Morrison formation</i> | | |
| <i>Sundance formation</i> | | |
| Upper Sundance | | |
| Soft thin shaly sandstone beds alternating with gray shales. | 19 | 0 |
| Massive sandstone bed containing very poorly preserved pelecypods in the upper portion. Cross-laminated and ripple-marked in places. | 18 | 0 |
| Very soft shales and sandstones. | 12 | 0 |
| Very fossiliferous resistant sandstone containing thin shales in places. It is cross-laminated and ripple-marked near the base and contains poorly preserved large pelecypods 2 inches in diameter. | 14 | 0 |
| Cross-laminated and ripple-marked gray sandstone with some thin fossiliferous beds containing <i>Kallirhynchia myrina</i> , <i>Ostrea</i> sp., and <i>Camptonectes</i> sp. Becomes much more massive and less fossiliferous near the base. | 65 | 0 |
| Dark shales with limonitic sandstone band at top containing a very fossiliferous bed from which was collected <i>Belemnites densus</i> , <i>Camptonectes</i> sp., and <i>Pentacrinus asteriscus</i> . | 10 | 0 |
| Dark gray shales containing small sandstone fragments at the top and many belemnites. Becomes more sandy near the base. | 52 | 0 |
| Black to gray fine-bedded shales containing some yellow limonitic beds and an abundance of <i>Belemnites densus</i> . They also contain well polished and highly rounded chert pebbles. A fragment of a worn ammonite (<i>Cardioceras</i> sp.) was collected from this bed. | 18 | 0 |
| Thin-bedded platy black to gray calcareous shale containing <i>Gryphaea calceola</i> var. <i>nebrascensis</i> in abundance. | 115 | 0 |
| Gray to black soft shales containing <i>Gryphaea calceola</i> var. <i>nebrascensis</i> in abundance. A 4-inch sand is present at the base from which was collected <i>Dosinia jurassica</i> , <i>Pleuromya newtoni</i> ?, many gastropods, and a large ammonite. | 16 | 0 |
| Tan to white marls alternating with gray shales and containing numerous fossils. | 9 | 0 |
| Erosion surface indicated by a sharp lithologic change. | 348 | 0 |
| Lower Sundance | | |
| Red sandy shales containing many gypsum seams and nodules. | 85 | 0 |
| Alternating buff to yellow sandy beds and gray to black shales. A lenticular bed of gypsum 6 inches thick is present locally at the top. <i>Camptonectes</i> sp., <i>Ostrea</i> sp., and other genera are present. The basal contact appears to be irregular. | 39 | 0 |
| | 124 | 0 |
| Total. | 472 | 0 |
| <i>Chugwater formation</i> | | |

Big Horn Basin-Kane.—A section of the Sundance formation, measured on the south flank of the Big Horn Mountains, near the point where the Big Horn River cuts through the mountains, and not far from the town of Kane (Fig. 1), comprises 336 feet of sandstones, shales, limestones, and red beds. This locality is approximately 50 miles northeast of the Cody section, and the beds have thinned more than 100 feet in that distance (Table X).

TABLE X
STRATIGRAPHIC SECTION OF SUNDANCE FORMATION MEASURED IN BIG HORN COUNTY,
WYOMING, ON THE WEST FLANK OF BIG HORN MOUNTAINS, NEAR THE
HEAD OF BIG HORN CANYON, IN SEC. 12, T. 57 N., R. 95 W.

| | Feet | Inches |
|--|------|--------|
| <i>Morrison?</i> sandstone | | |
| Sundance formation | | |
| Upper Sundance | | |
| Resistant cross-bedded sandstone forming a ledge..... | 25 | 0 |
| Very fossiliferous sandstone containing <i>Ostrea</i> sp., and <i>Pleuromya?</i> sp. Cross bedding and ripple marks are present in thin beds which are not fossiliferous..... | 10 | 0 |
| Soft gray to buff and black shales containing <i>Belemnites densus</i> in abundance near the base. Land-slide conditions did not permit de- tailed measurement. <i>Ostrea</i> sp. and <i>Kallirhyncha?</i> sp. were also col- lected from these beds..... | 123 | 0 |
| White thin-bedded shale..... | 10 | 0 |
| Extremely thin-bedded platy sandy and calcareous shale..... | 15 | 0 |
| Soft gray shale containing <i>Gryphaea calceola</i> var. <i>nebrascensis</i> in abundance..... | 40 | 0 |
| | 223 | 0 |
| Erosion surface indicated by a sharp lithologic change. | | |
| Lower Sundance | | |
| Alternating sandy, shaly, and calcareous beds containing <i>Pentacrinus</i> <i>asteriscus</i> , <i>Trigonia quadrangularis</i> , <i>Dosinia jurassica</i> , <i>Ostrea</i> sp., <i>Volsella?</i> sp., <i>Mytilus?</i> sp., and small gastropods..... | 18 | 0 |
| Red beds containing gypsum..... | 75 | 0 |
| Alternating massive and thin-bedded black limestones which weather white. Pinkish to red marly shales, sands, and gypsum beds..... | 30 | 0 |
| | 123 | 0 |
| Total..... | 346 | 0 |
| <i>Chugwater?</i> red beds | | |

Big Horn Basin—Thermopolis.—The Sundance formation is 280 feet thick on the north flank of the Thermopolis anticline, 4 miles north of the town of Thermopolis (Fig. 1). This locality is about 90 miles south of the section which was measured near Kane.

Correlation between the Cody, Kane, and Thermopolis sections.—The correlation of these three sections is very similar to that along the northeast flank of the Wind River Mountains. Fossiliferous beds in the upper part of the section at Cody are absent from the sections

at Kane and Thermopolis (Fig. 3). The *Belemnites* zone is present in all three sections and can be correlated. Below the *Belemnites* zone, as in the sections measured along the northeast flank of the Wind River Mountains, there is evidence of erosion. Well rounded chert pebbles and sandy beds occur in the section at Cody, and sandy beds are present immediately below the *Belemnites* zone in the sections measured at Kane and Thermopolis. The *Gryphaea* zone is present at Cody and Kane, but is absent at Thermopolis.

TABLE XI

STRATIGRAPHIC SECTION OF SUNDANCE FORMATION MEASURED ON THE
NORTH FLANK OF THERMOPOLIS ANTICLINE, 4 MILES NORTH OF
THERMOPOLIS, WYOMING, IN SEC. 35, T. 43 N., R. 95 W.

| | Feet Inches | |
|---|-------------|---|
| <i>Morrison?</i> sandstone | | |
| Sundance formation | | |
| Upper Sundance | | |
| Massive to thin-bedded cross-laminated conglomeratic sandstone. . . . | 50 | 0 |
| Dark gray and greenish shales. | 35 | 0 |
| Massive white friable sandstone. | 35 | 0 |
| Thin-bedded sandstone. | 25 | 0 |
| Soft gray shales with thin beds of very fossiliferous limestone containing an abundance of <i>Camptonectes</i> sp. <i>Belemnites densus</i> was collected from the shales. The absence of <i>Gryphaea calceola</i> var. <i>nebrascensis</i> is very noteworthy. | 100 | 0 |
| Cross-laminated thin-bedded ripple-marked sandstone grading downward into a fine-grained conglomerate. | 10 | 0 |
| | 255 | 0 |
| Erosion surface evidenced by the presence of a conglomerate and a sharp lithologic change. | | |
| Lower Sundance | | |
| Pink to red and white shales, sandy and marly at the base.* Contains <i>Trigonia quadrangularis</i> and a gastropod. | 25 | 0 |
| Total. | 280 | 0 |
| <i>Chugwater?</i> red beds | | |

* In regard to this section, Reeside¹⁶ made the following statement: "There is a conspicuous zone of red beds, under which lies a fossiliferous marine limestone several feet thick. It is decidedly not Alcova, faunally or lithologically, and must be part of the Jurassic."

Red beds occur below the *Gryphaea* zone at Cody and Kane, and below the *Belemnites* zone at Thermopolis. Here again, as in the Wind River Mountains, there is a sharp break between the fossiliferous dark marine shales and the red sandstone, red shale, and gypsum, and it is believed that this represents a period of erosion during which time the sea had retreated from this area. At the top of the red beds at Cody there is a fossiliferous marl from which *Trigonia*, *Dosinia*, and numerous gastropods were collected. Below the red beds, 30 feet of sandstones and shales are present from which were collected *Ostrea*,

¹⁶ John B. Reeside, Jr., personal communication (1937).

Camptonectes, *Volsella*, and *Mytilus*. No fossils were found within or below the red series at Kane, although *Trigonia quadrangularis* and small gastropods have been collected from the red beds at Thermopolis.

Shirley Mountain-Muddy Gap.—A section measured at Muddy Gap, in the Shirley Mountains (Fig. 1), contains 275 feet of Sundance. The upper sandy series is present at this locality and below the sandy series the *Belemnites* zone occurs. Below the *Belemnites* zone are unfossiliferous shales, red beds, and sandstones. The exposure at this locality is not good enough to portray further details of the section.

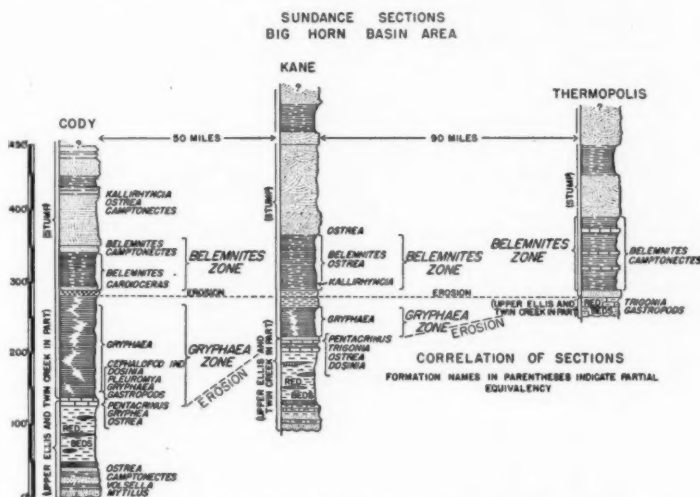


FIG. 3.—Correlation of the Cody, Kane, and Thermopolis sections.

Rattlesnake Hills.—The Sundance section at Rattlesnake Hills (Fig. 1) is very similar to that at Muddy Gap. The *Belemnites* zone is present and the general lithologic relations appear to be the same.

Alcova.—The Sundance formation at Alcova (Fig. 1) comprises 264 feet of sandstones, shales, and red beds. The *Belemnites* zone persists throughout this area. Table XII shows a section of the Sundance formation measured at Alcova.

Freezeout Hills-Trabing Brothers Spring (T. B. Spring).—There are excellent exposures of the Sundance formation near Trabing Brothers Spring, in the Freezeout Hills (Fig. 1). The following section was measured at that locality.

TABLE XII
STRATIGRAPHIC SECTION OF SUNDANCE FORMATION MEASURED
4 MILES SOUTH OF THE TOWN OF ALCOVA, NATRONA
COUNTY, WYOMING

| | Feet Inches | |
|--|-------------|----|
| <i>Morrison?</i> sandstone | | |
| Sundance formation | | |
| Upper Sundance | | |
| Fine-grained calcareous massive to thin-bedded unfossiliferous soft sandstone containing limonite concretions. This bed forms a ledge in places and has a pinkish coating from the overlying shales. Fresh fractures are yellow. It appears to be cemented with a calcareous cement. | 25 | 0 |
| Thin-bedded black platy shale bed which has a more or less irregular and lenticular form. No fossils were found. | 0 | 10 |
| Fine-grained sandstone, much the same as above. | 2 | 0 |
| Unfossiliferous irregular thin-bedded platy black shale. | 0 | 8 |
| Fine-grained thin-bedded white to yellowish sandstone containing a few limonite concretions. Cross-laminated on a very small scale. | 4 | 6 |
| Alternating beds of white thin-bedded shaly sandstones and unfossiliferous black shales. The sandstone contains fucoids. | 4 | 0 |
| Platy unfossiliferous dark red to maroon shale. | 1 | 0 |
| Soft platy unfossiliferous black shale. | 3 | 0 |
| Blocky thin-bedded crinkly gray limestone. | 1 | 0 |
| Very fine-bedded platy unfossiliferous dark gray to black shale. | 5 | 0 |
| Ripple and fucoid-marked platy thin-bedded fine to medium-grained sandstone containing fragments of pelecypod shells. | 9 | 0 |
| Alternating sandy and calcareous beds with dark platy shale in which <i>Camptonectes</i> sp. is abundant. A few specimens of <i>Belemnites densus</i> were also found. | 17 | 0 |
| Very fossiliferous marly clay containing an abundance of <i>Camptonectes</i> sp., <i>Ostrea</i> sp., <i>Ostrea strigilecula</i> , and a few specimens of <i>Gryphaea</i> ? sp. | 1 | 0 |
| Soft green to dark gray shales with a 2-foot bed of fine-grained thin-bedded sandstone at the base. | 4 | 6 |
| Soft black shales with <i>Belemnites densus</i> in abundance. | 65 | 0 |
| | 143 | 6 |
| Erosion surface indicated by a sharp lithologic change | | |
| Lower Sundance* | | |
| Very fine-grained white shaly sandstone, darker on fresh surfaces. | 4 | 0 |
| Deep red soft sandy shale. | 2 | 0 |
| Gray shale. | 1 | 0 |
| Pink fine-grained resistant shaly sandstone. | 5 | 0 |
| Soft red sands with occasional thin white sandy beds. | 20 | 0 |
| White gypsum bed. | 8 | 0 |
| Fine-grained white sand. | 1 | 0 |
| Dark red to pink fine-grained shaly sand. | 25 | 0 |
| Fine-grained platy sand with shale partings. | 6 | 0 |
| Fine-grained thin-bedded brown sandstone containing ripple marks. | 4 | 0 |
| Soft green platy unfossiliferous shales. The basal four feet is of a maroon color. | 25 | 0 |
| White to gray fine-grained thin-bedded to massive basal sand with irregular basal contact. | 20 | 0 |
| | 121 | 0 |
| Total. | 264 | 6 |
| <i>Jeil</i> formation | | |

* Reeside²⁰ reports a thin bed containing *Tellina*-like pelecypods, having no chronologic meaning but suggesting marine origin, from somewhere in the lower part of the Alcova section.

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TABLE XIII

STRATIGRAPHIC SECTION OF SUNDANCE FORMATION MEASURED NEAR TRABING
BROTHERS SPRING, IN FREEZEOUT HILLS, T. 24 W., R.
78 N., CARRON COUNTY, WYOMING

| Morrison formation | | Feet | Inches |
|--|-----|------|--------|
| Sundance formation | | | |
| Upper Sundance | | | |
| Thin-bedded shaly cross-laminated buff to light gray sandstone, topographically prominent..... | 11 | 0 | |
| Soft black flaky shales which weather gray. A bed of sandstone occurs near the top from which was collected <i>Ostrea</i> sp..... | 12 | 0 | |
| Very thin-bedded cross-laminated sandstone..... | 3 | 0 | |
| Black flaky shales which weather gray and form a depression. They contain <i>Cardioceras</i> sp. and <i>Ostrea strigilecula</i> | 27 | 6 | |
| Soft gray flaky shales containing <i>Belemnites densus</i> | 19 | 6 | |
| Sandstone bed..... | 0 | 6 | |
| Soft gray shales containing <i>Belemnites densus</i> in abundance..... | 33 | 0 | |
| | 106 | 6 | |
| Erosion surface indicated by sharp lithologic change | | | |
| Lower Sundance | | | |
| White to buff to pinkish fine-grained sandstone. This bed is cross-laminated on a minute scale and is prominent topographically..... | 4 | 6 | |
| Flaky black shale which weathers light gray. Contains a sandstone in the middle 4 feet thick..... | 6 | 0 | |
| Soft red sandy shale forming a depression..... | 24 | 0 | |
| Buff to gray resistant cross-laminated sand..... | 3 | 0 | |
| Soft sandy shale. Mottled red and white at the top and red through most of the bed..... | 5 | 6 | |
| Thin-bedded fine-grained white sandstone topographically prominent..... | 3 | 6 | |
| Red sandy shale forming a depression..... | 5 | 6 | |
| Very soft friable white sandstone forming a depression..... | 25 | 0 | |
| Resistant cross-laminated buff sandstone..... | 8 | 0 | |
| Soft gray to buff shaly sandstone forming a depression..... | 5 | 0 | |
| | 90 | 0 | |
| Unconformity? | | | |
| (Nugget?) | | | |
| White to buff, weathering steel gray, cross-laminated friable sandstone forming a cliff. The basal portion is coarse-grained. The cross bedding is on a large scale and very pronounced..... | 128 | 0 | |
| | 128 | 0 | |
| Total..... | 324 | 6 | |
| Jelm formation | | | |

Medicine Bow Mountains-Wagonhound Creek.—A section measured at the locality where Wagonhound Creek cuts through the Sundance formation, on the north end of the Medicine Bow Mountains (Fig. 1), comprises approximately 75 feet of shales and sandstones. The shales predominate and the *Belemnites* zone is present. There are no red beds present at this exposure, and the sandstones are very thin.

Centennial Valley.—The Sundance formation is represented by 45 feet of shales and some thin sandstones at an exposure near the town

TABLE XIV

STRATIGRAPHIC SECTION OF THE SUNDANCE FORMATION MEASURED IN
CENTENNIAL VALLEY, NEAR THE TOWN OF CENTENNIAL, ALBANY
COUNTY, WYOMING, IN SEC. 3, T. 15 N., R. 78 W.

| <i>Morrison formation</i> | | | |
|--|----|-------------|--|
| <i>Sundance formation</i> | | Feet Inches | |
| Upper Sundance | | | |
| Thin-bedded fine-grained platy white sandstones. | 2 | 0 | |
| Soft unfossiliferous light gray shales forming a depression. | 9 | 0 | |
| Medium-grained friable white to yellow sandstone. | 5 | 0 | |
| Soft gray shales forming a depression. Contains <i>Belemnites densus</i> in abundance. | 14 | 0 | |
| Coarse-grained cross-bedded friable gray sandstone containing <i>Belemnites densus</i> and fragments of other fossils. Calcite seams and secondary chert are present in this sandstone. | 1 | 0 | |
| Soft yellow thin-bedded sandy shale. This bed contains <i>Belemnites densus</i> in abundance in the upper part. The exposure forms a depression. | 11 | 0 | |
| Fine-grained yellowish friable sandstone forming a slight ridge where exposed. It ranges from massive to thin-bedded and contains fucoid markings and slickensides. Beneath the sand and above the red beds are yellow and black shales which grade into the sand above. The lower contact seems to be slightly irregular. | 3 | 6 | |
| | 45 | 6 | |
| <i>Jelm formation</i> | | | |

TABLE XV

STRATIGRAPHIC SECTION OF SUNDANCE FORMATION MEASURED ON THE SOUTH
FACE OF BULL MOUNTAIN, COLORADO, SOUTH OF THE WYOMING-
COLORADO STATE LINE, IN SEC. 30, T. 11 N., R. 76 W.

| <i>Morrison formation</i> | | | |
|---|----|-------------|--|
| <i>Sundance formation</i> | | Feet Inches | |
| Upper Sundance | | | |
| Yellowish gray fine-grained thin and even-bedded unfossiliferous shaly sandstone. The sand is friable and forms a gentle slope. | 6 | 0 | |
| Massive friable medium to fine-grained unfossiliferous sandstone forming a slight topographic expression. | 2 | 6 | |
| Alternating black and yellowish bands of soft flaky shale. | 2 | 0 | |
| Resistant yellow to brown quartzitic sandstone. | 0 | 3 | |
| Soft unfossiliferous dark gray flaky shale. | 0 | 10 | |
| Very resistant brown quartzitic bed. | 0 | 4 | |
| Unfossiliferous gray flaky shales with thin beds of brown sandstone. | 3 | 0 | |
| Soft yellow sandy shale, thin and even-bedded. | 5 | 0 | |
| Massive to thin-bedded alternating medium to fine-grained friable yellow shaly sandstone. Becomes orange-colored near the base and contains a thin flaky green shale near the middle. | 6 | 0 | |
| Massive cross-bedded resistant yellowish to orange to pink mottled sandstone of medium to fine-grained texture. The cross bedding is not pronounced. | 18 | 0 | |
| Massive uniformly medium-grained resistant gray sandstone with no pronounced cross bedding. At the base of this bed there is an irregular erosion surface. | 10 | 0 | |
| Extremely cross-bedded, predominantly yellow, but also orange and pink, coarse to fine-grained resistant sandstone forming a ridge. The cross bedding is of a large magnitude with high-angle discordances cut off sharply both above and below by extremely flat even surfaces | 24 | 0 | |
| Total. | 77 | 11 | |
| <i>Jelm formation</i> | | | |

TABLE XVI

STRATIGRAPHIC SECTION OF SUNDANCE FORMATION MEASURED ON
THE HILL $\frac{1}{4}$ MILE NORTHEAST OF THE TOWN OF SPEARFISH,
SOUTH DAKOTA, IN THE BLACK HILLS

| | | Feet | Inches |
|--|-----|------|--------|
| <i>Morrison shales</i> | | | |
| <i>Sundance formation</i> | | | |
| Upper Sundance | | | |
| Yellow limonitic sandstone, resistant and unfossiliferous. Breaks up into blocks and forms yellow soil. | 3 | 0 | |
| Soft black shales which weather gray and contain lime concretions. No fossils were observed. | 16 | 0 | |
| Hard, resistant yellow sandstone which weathers brown and contains many fragments of pelecypod shells and large worm borings. This bed is ripple-marked in places and from it were collected <i>Ostrea strigilecula</i> , <i>Camptonectes bellistriatus</i> , and large <i>Ostrea</i> sp. It also contains many lime concretions and grades downward into platy thin-bedded shaly sand. | 3 | 0 | |
| Shaly sand, grading downward into soft gray shales which form gentle slopes. Occasional lime concretions are present and contain fossils. . . | 45 | 0 | |
| Thin limestone beds containing <i>Eumicrolis curta</i> and <i>Pleuromya</i> sp. in abundance. | 0 | 6 | |
| Soft black shale which weathers gray and contains <i>Belemnites densus</i> in abundance. Forms a gentle slope and contains occasional limestone beds which are extremely fossiliferous. | 41 | 0 | |
| Light-colored soft sandy shale which grades downward into soft shaly sandstone. There are occasional limonite concretions. No fossils were observed. The basal member of this sand is somewhat cross-bedded and lies with an irregular wavy contact on red sandy shale. . . | 20 | 0 | |
| | 128 | 6 | |
| Erosion surface indicated by an irregular surface and a sharp lithologic change. | | | |
| Lower Sundance | | | |
| Soft red unfossiliferous sandy shales containing small gypsum spheres and gypsum seams. | 45 | 0 | |
| Greenish yellow shaly sandstone. Very soft, friable, and poorly cemented. No fossils were observed. | 24 | 0 | |
| Soft pinkish sandy shale. | 4 | 0 | |
| Gray to yellow thin-bedded sand and alternating pinkish shale. | 5 | 0 | |
| A succession of resistant fine to medium-grained sandstones, some massive and some thin-bedded, slightly cross-bedded, from dark brown to pinkish to buff in color and containing some shaly members. Large ripple marks are present at several horizons and all seem to trend north-south. | 20 | 0 | |
| Soft thin-bedded greenish shales forming gentle slopes. No fossils were observed. | 30 | 0 | |
| Dark gray to buff sandy shales. No fossils were observed. | 13 | 0 | |
| | 141 | 0 | |
| Total. | 269 | 6 | |
| <i>Spearfish formation</i> | | | |
| The top of the Spearfish is a thick gypsum bed and the nature of the contact is obscured. | | | |

of Centennial, in Centennial Valley (Fig. 1). The *Belemnites* zone is present at this locality and *Belemnites densus* is the most characteristic and abundant fossil in the entire section (Table XIV).

Colorado-Bull Mountain.—The Sundance formation on the south

face of Bull Mountain, Colorado (Fig. 1), is represented by 78 feet of unfossiliferous sandstone containing a few black shale partings. No fossils were observed in the formation at this locality (Table XV).

Black Hills-Sundance.—The Sundance at the type locality, near the town of Sundance, in the Black Hills (Fig. 1), is approximately 400 feet thick. The exposures near this locality are very good in places, but it is difficult to find a continuous section exposed from the base to the top, and for this reason the thickness specified is probably not accurate. A much better exposed section was measured on the hill northeast of the town of Spearfish, South Dakota (Fig. 1), which is 30 miles northeast of Sundance.

South Dakota-Spearfish.—The Sundance formation at Spearfish, South Dakota, is 269 feet thick. The *Belemnites* zone is present in this section. Table XVI shows a section of the Sundance measured at this locality.

AGE AND STRATIGRAPHIC RELATIONS

The Sundance formation rests unconformably on Triassic rocks and is overlain unconformably by the Morrison formation. The unconformity at the top of the Sundance formation is made evident in most places only by the change from marine to continental sediments, which in many places appears to be gradational from Sundance to Morrison. As far as can be determined, there is no angular discordance, and the time interval separating the two formations might be almost negligible. However, there must almost certainly have been some erosion taking place with the removal of the marine environment and deposition of stream sediments. The unconformity at the base of the Sundance is not well evidenced by physical relations, although in some places an irregular contact can be seen. There is certainly an unconformity of long time value at the base of the Sundance to account for all of Lower and Middle Jurassic, none of which seems to be represented in the Sundance formation in most exposures, the Freezeout Hills section being a possible exception. Crickmay⁵⁶ assigns the Sundance to an Argovian-Kimmeridgian age with respect to the European section, with the questionable reference of the basal sandstone to the basal Ellis of the Yellowstone National Park region which he considers to be of Callovian age. Baker, Dane, and Reeside⁵⁷ refer to the Curtis formation of Utah as being partially equivalent to the Sundance.

⁵⁶ *Op. cit.*, pp. 541-64.

⁵⁷ *Op. cit.*, p. 47.

CORRELATION OF FORMATIONS

NUGGET SANDSTONE

The Nugget sandstone has been tentatively correlated with the basal sandstone member of the Sundance formation in the limited area of Freezeout Hills in southeastern Wyoming (Figs. 1, 5, and 6). This correlation has been based solely on lithologic similarity, stratigraphic position, and the evidence of an unconformable relationship at the top of the sandstone. Bartram⁵⁸ has correlated the basal Sundance sand with the Nugget formation and believed that this can be traced from western Wyoming to the Black Hills. However, the presence of a marine fauna not found in the Nugget, in the basal Sundance sandstone at certain localities, and the absence of any evidence of an erosion surface at the top of the basal sandstone, tends to disprove this correlation for all of the localities except that in the vicinity of Freezeout Hills.

The Nugget formation is apparently of continental origin, and, although one fossil has been reported from it in the Wasatch Mountains, in all other localities it seems to be unfossiliferous. To the south, in southern Utah, it is said to have an eolian origin and is thought to be equivalent to the Navajo sandstone.⁵⁹

TWIN CREEK FORMATION

The Twin Creek formation is here correlated, in part at least, with the lower portion of the Sundance formation, or that portion of the Sundance which is below the major erosion surface, and with the Ellis formation as defined by Crickmay,⁶⁰ the limestone and shale series of the Ellis formation as it was originally described by Hague⁶¹ (Figs. 5 and 6). This correlation has been based on the following considerations. 1. Evidence of an erosion surface at the top of the Twin Creek limestone, at the top of the Ellis formation as defined by Crickmay,⁶² and within the Sundance formation. 2. Faunal relations between the Twin Creek limestone, the Ellis formation, and that portion of the Sundance formation below the major erosion surface. 3. The presence of red sandstones, red shales, and gypsum beds beneath the major erosion surface within the Sundance formation. 4. The presence, in certain isolated eastern localities, of remnants of

⁵⁸ John G. Bartram, *op. cit.*, pp. 335-45.

⁵⁹ A. A. Baker, C. H. Dane, and J. B. Reeside, Jr., *op. cit.*, p. 6.

⁶⁰ *Op. cit.*, p. 552.

⁶¹ *Op. cit.*, p. 5.

⁶² *Op. cit.*, p. 552.

limestone in the lower shales, below the red beds, which contain *Pentacrinus asteriscus*, a fossil which is extremely common and abundant in the Twin Creek formation and which is rare in the upper Sundance.

EVIDENCE OF AN EROSION SURFACE

The contact between the Twin Creek limestone and the Preuss formation has been generally considered an unconformable one,⁶³ and from the evidence seen in the field, the writer believes this to be the fact. The presence of a hiatus between the Ellis and the Sundance formation in the Yellowstone National Park region has been pointed out by Crickmay⁶⁴ as shown by a faunal break. Evidence of an erosion surface within the Sundance formation in the regions of the Wind River Mountains and the Big Horn Basin has been referred to in the preceding pages of this paper (Figs. 2 and 3). The distinct and sharp change in the lithology within the Sundance formation, between the red gypsiferous sandstones and red shales and the overlying dark fossiliferous marine shales, is considered as evidence of an erosional break within the formation. At Spearfish, South Dakota (Table XVI), there is an irregular contact between the red beds and the overlying fossiliferous shales, and at Thermopolis (Table XI), a conglomerate is associated with the change in lithology.

Brainerd and Keyte,⁶⁵ in speaking of the red beds in the lower part of the Sundance formation, make the following statement:

It is suggested that this zone should, when thoroughly outlined, be given a new name and placed in the Jurassic. It appears to the writers that this would make for simpler stratigraphy than to include these red shales in the typical Sundance, inasmuch as there appears to be a definite break between the two.

The red beds within the Sundance formation in northwestern Wyoming, the region to which Brainerd and Keyte referred, has apparently been mapped as Chugwater (Triassic), although there are red beds in the Sundance type section which are probably equivalent to them.

For convenience, in this paper, the portion of the Sundance below this major erosion surface will be referred to as lower Sundance, and the portion above the break, as upper Sundance.

⁶³ George Rogers Mansfield, *op. cit.*, p. 99; and G. R. Mansfield and P. V. Roundy, *op. cit.*, p. 81.

⁶⁴ *Op. cit.*, p. 553.

⁶⁵ *Op. cit.*, p. 752.

FAUNAL RELATIONS

The faunas which have been collected and reported from the Twin Creek, the lower Sundance, and the Ellis formation as defined by Crickmay, are similar, but hardly conclusive as to exact correlation. Twin Creek fossils are typically widely scattered and poorly preserved, and identification of the more diagnostic ammonites has been impossible. Fossils from the Ellis formation are common, especially the pelecypods, and many have been reported by various authors. In the lower Sundance, fossils are scarce and are chiefly pelecypods. However, the absence of very common and abundant fossils which characterize the upper Sundance seems to indicate almost conclusively that the Twin Creek, Ellis and lower Sundance are in no part equivalent to the upper Sundance. The two most common upper Sundance fossils are *Belemnites densus* and *Gryphaea calceola* var. *nebrascensis*, and the writer has never collected these from the Twin Creek or the lower Sundance, and they have not been reported from the Ellis of Crickmay.

The following fossils have been collected from the Twin Creek limestone.⁶⁶

Gryphaea planoconvexa Whitfield
Dosinia jurassica Whitfield
Pleuromya subcompressa Meek
Pleuromya autolycus Crickmay
Pleuromya sp.
Astarte packardii White
Ostrea strigilecula White
Ostrea sp.
Camptonectes stygius White
Camptonectes plaessiformis White
Camptonectes sp.
Trigonia quadrangularis Hall and Whitfield
Trigonia montanaensis Meek
Trigonia americana Meek
Trigonia sp.
Gervillia montanaensis Meek
Gervillia cf. *G. montanaensis* Meek
Pholadomya kingii Meek
Pentacrinus asteriscus Meek and Hayden
Lima occidentalis Hall and Whitfield
Pinna sp.
Tancredia sp.
Parapecten sp.
 Eight specimens of ammonites
 Several specimens of brachiopods

Fossils have been reported from the Twin Creek by Mansfield,⁶⁷ and those which the writer has not collected include the following.

⁶⁶ For localities and horizons from which these fossils were collected see Tables II, III, IV, and V.

⁶⁷ *Op. cit.*, p. 98, Pl. 31.

Serpula sp.
Pecten sp.
Camptonectes pertenuistriatus Hall and Whitfield?
Gryphaea calceola var. *nebrascensis* Meek and Hayden
Perisphinctes sp.

The listing of *Gryphaea calceola* var. *nebrascensis* is rather puzzling. This fossil is very common in the upper Sundance, but the writer was unable to find one in the Twin Creek at any of the localities visited which was a true *Gryphaea calceola* var. *nebrascensis*.

The following fossils have been reported from the Ellis as defined by Crickmay.⁶⁸

Trigonia americana Meek
Camptonectes distans Stanton
Camptonectes platessiformis White
Gervillia montanaensis Meek
Gervillia cf. *sparsilirata* Whitfield
Gervillia dolabrata Crickmay
Astarte meeki Stanton
Astarte morion Crickmay
Pinna kingii Meek
Ostrea strigilecula White
Pleuromya subcompressa Meek
"Dosinia" sp.
Pentacrinus sp.
Grammatodon sp.
Lima aff. *cinnabarensis* Stanton
Tancredia sp.
Mytilus sp.

The following fossils were reported and described from the Ellis formation by C. A. White.⁶⁹ These fossils were collected at random, and while most of them probably came from the lower Ellis, or the Ellis as defined by Crickmay, some of them may have been collected from the overlying upper Ellis beds.

Camptonectes platessiformis Meek
Gervillia montanaensis Meek
Volsella subimbricata Meek
Trigonia montanaensis Meek
Trigonia americana Meek
Astarte packardii White
Pholadomya kingii Meek
Goniomya montanaensis Meek
Pleuromya subcompressa Meek

The following fossils were collected from the lower Sundance.⁷⁰

Trigonia quadrangularis Hall and Whitfield
Trigonia sp.

⁶⁸ *Op. cit.*, pp. 546-51.

⁶⁹ C. A. White, "Jurassic Fossils from the Western Territories," *U. S. Geol. and Geog. Survey Territories of Wyoming and Idaho* (1878), pp. 143-53.

⁷⁰ For the localities and horizons from which these fossils were collected see Tables V, VI, IX, X, and XI.

Dosinia jurassica Whitfield
Pentacrinus asteriscus Meek and Hayden
Tancredia inornata? Meek and Hayden
Tancredia sp.
Camptonectes sp.
Volsella sp.
Mytilus sp.
Ostrea sp.
 Several specimens of gastropods.

Brainerd and Keyte⁷¹ reported the following fossils from red beds in the lower Sundance in the Pryor Mountains of northwestern Wyoming. The collection was made from beds which had been mapped as Chugwater (Triassic).

Stylina sp.
Ostrea strigilecula White
Lima occidentalis Hall and Whitfield
Modiolus subimbricatus Meek?
Trigonia quadrangularis Hall and Whitfield
Astarte? sp.
Pleuromya subelliptica Meek and Hayden
Nerinea sp.
Quenstedticeras? sp.

Of the fossils previously listed, the following are common to the Ellis of Crickmay, the Twin Creek, and the lower Sundance (Table XVII).

TABLE XVII

FOSSILS COMMON TO THE ELLIS, TWIN CREEK, AND LOWER SUNDANCE FORMATIONS

| Fossil | Ellis | Twin Creek | Lower Sundance |
|--|-------|------------|----------------|
| <i>Camptonectes platessiformis</i> | × | × | |
| <i>Gervillia montanaensis</i> | × | × | |
| <i>Gryphaea planoconvexa</i> | × | × | |
| <i>Pleuromya subcompressa</i> | × | × | |
| <i>Pentacrinus asteriscus</i> | × | × | × |
| <i>Pholadomya kingii</i> | × | × | |
| <i>Trigonia quadrangularis</i> | | × | × |
| <i>Trigonia americana</i> | × | × | × |
| <i>Trigonia montanaensis</i> | × | × | |
| <i>Ostrea strigilecula</i> | × | × | × |
| <i>Astarte packardii</i> | × | × | × |
| <i>Mytilus</i> sp..... | × | | × |
| <i>Dosinia</i> sp..... | × | × | × |
| <i>Lima occidentalis</i> | | × | × |
| <i>Tancredia</i> sp..... | × | × | × |
| <i>Camptonectes</i> sp..... | × | × | × |

The faunal similarity between the Twin Creek, the Ellis of Crickmay, and the lower Sundance, and the absence of the very commonly occurring fossils of the upper Sundance, upper Ellis (Sundance of Crickmay in the Yellowstone National Park region), and the Stump,

⁷¹ *Op. cit.*, pp. 747-52.

such as *Belemnites densus* and *Gryphaea calceola* var. *nebrascensis*, point toward this correlation.

LOWER SUNDANCE RED BEDS

Most of the sections of the Sundance formation which were observed are characterized by the presence of red sandstone, red shale, and gypsum beds which occur beneath the fossiliferous dark shales. The red beds are lenticular, and in some localities, such as at Alcova (Fig. 1), contain considerable gypsum. The typical red beds are not fossiliferous. The fossils of the lower Sundance have been collected from sandstones and marls below, within, or at the top of the red beds. These sediments were probably deposited in inland lakes, and by evaporation from undrained depressions, although some portions of them are undoubtedly marine and probably represent the shore facies sediments deposited in the marginal lagoons and bays of the retreating Twin Creek sea. In the writer's opinion, this is strong evidence of the retreat of the sea and a period of erosion. The erosion surface at the top of the red beds corresponds in position in the formation to the position of the erosion surface at the top of beds of Twin Creek age in the western part of the state, and tends to strengthen the belief that a general period of erosion took place before the deposition of the typical fossiliferous upper Sundance.

FOSSILIFEROUS LIMESTONE REMNANTS IN THE LOWER SUNDANCE SHALES

Remnants of limestone containing *Pentacrinus* sp. have been reported from the lower Sundance shales in the Black Hills and also in southeastern Wyoming.⁷² This fossil is extremely abundant in the Twin Creek limestone and comparatively rare in the upper Sundance. This appears to be another fragment of evidence which tends to substantiate the belief that there was a period of erosion, and that these limestones are merely erosional remnants which were not removed.

PREUSS FORMATION

The unfossiliferous Preuss formation is apparently a delta deposit, partly of continental and partly of marine origin. As far as the writer has been able to determine, the lower part of the Stump formation is probably of the same age as a portion of the Preuss, the contact between the two being one of gradation between delta red beds and marine sandstones. The lower part of the upper Sun-

⁷² Willis T. Lee, *op. cit.*, p. 39; N. H. Darton, "Description of the Sundance Quadrangle," *U. S. Geol. Survey Atlas Folio* (1905), p. 3; S. H. Knight, oral communication (1936).

dance was probably deposited at the same time. The Preuss formation is thought to be equivalent to the Entrada sandstone of southern Utah by Baker, Dane, and Reeside,⁷³ the Entrada being correlated with the lower part of the Beckwith formation of southeastern Wyoming.

STUMP FORMATION

The Stump formation is believed to be partly equivalent to the upper Sundance of central and eastern Wyoming and is probably also equivalent in its lower part to the upper portion of the Preuss red

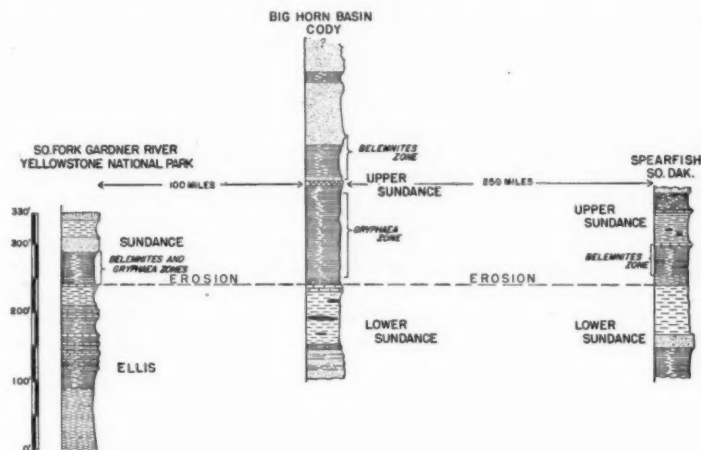


FIG. 4.—Correlation of sections from Yellowstone National Park to Spearfish, South Dakota.

beds. *Belemnites densus* occurs in abundance in the Stump formation in certain localities, and has also been reported from beds above the Stump.⁷⁴ Among other fossils which occur commonly in the Stump are *Camptonectes bellistriatus* and *Gryphaea calceola* var. *nebrascensis*. These fossils are extremely abundant in the upper Sundance of central and eastern Wyoming, and do not occur in the Twin Creek, the Ellis of Crickmay, or in the lower Sundance. It appears, from these faunal relations, that the Stump, the Sundance of Crickmay, and the upper Sundance of central and eastern Wyoming, are quite definitely correlatives.

⁷³ *Op. cit.*, p. 7.

⁷⁴ W. W. Rubey, oral communication (1936).

SUNDANCE FORMATION

From the foregoing evidence, the lower Sundance is thought to be equivalent in part to the Ellis formation of northwestern Wyoming and Montana, as the Ellis has been defined by Crickmay (Fig. 4), and to the Twin Creek limestone of southeastern Idaho and western Wyoming. The upper Sundance is thought to be equivalent to part of the Stump and the Preuss formations of southeastern Idaho and western Wyoming, and the Sundance formation as it has been defined by Crickmay, or the upper Ellis as it was originally defined, in northwestern Wyoming (Fig. 4). Bartram,⁷⁵ in 1930, suggested a correlation between the western and eastern Wyoming sections which is quite similar to the one presented by the writer. In referring to this correlation, Bartram says:

... Twin Creek of western Wyoming is correlated with the Sundance formation by everyone, but it is not known yet how the various units of the Sundance carry through into the very different section of the Twin Creek. ... Additional work can well be done between the western Wyoming area and the Wind River Mountains, perhaps in the Gros Ventre Mountains, to determine the exact relation of the Twin Creek to the various units of the Sundance. It is suggested here that the Twin Creek of western Wyoming may be largely equivalent to the lower and middle parts of the Sundance and with perhaps some of the upper part, and that the lower part of the Beckwith formation may be equivalent to at least some of the upper part of the Sundance.

AGE OF THE FORMATIONS

GENERAL STATEMENT

The age of the Wyoming Jurassic rocks compared to the European type section is beyond the scope of this paper. However, age assignments have been made by Crickmay for the Yellowstone National Park region, by Baker, Dane, and Reeside for the Utah Jurassic, and to some extent by Mansfield for the southeastern Idaho section. Moreover, personal communication with Reeside has thrown much controversial light on the subject. With the correlations which have been postulated by the writer in this paper, and the age assignments which have been made by authors for other regions, it is possible to approach the matter of dating the Wyoming Jurassic. This dating must necessarily depend upon two factors: first, the correctness of the correlations which have been presented in this paper, and second, the correctness of the age assignments which have been made by authors for the various regions surrounding the area in question. The evidence has been presented in this paper for the first consideration,

⁷⁵ *Op. cit.*, pp. 342-43.

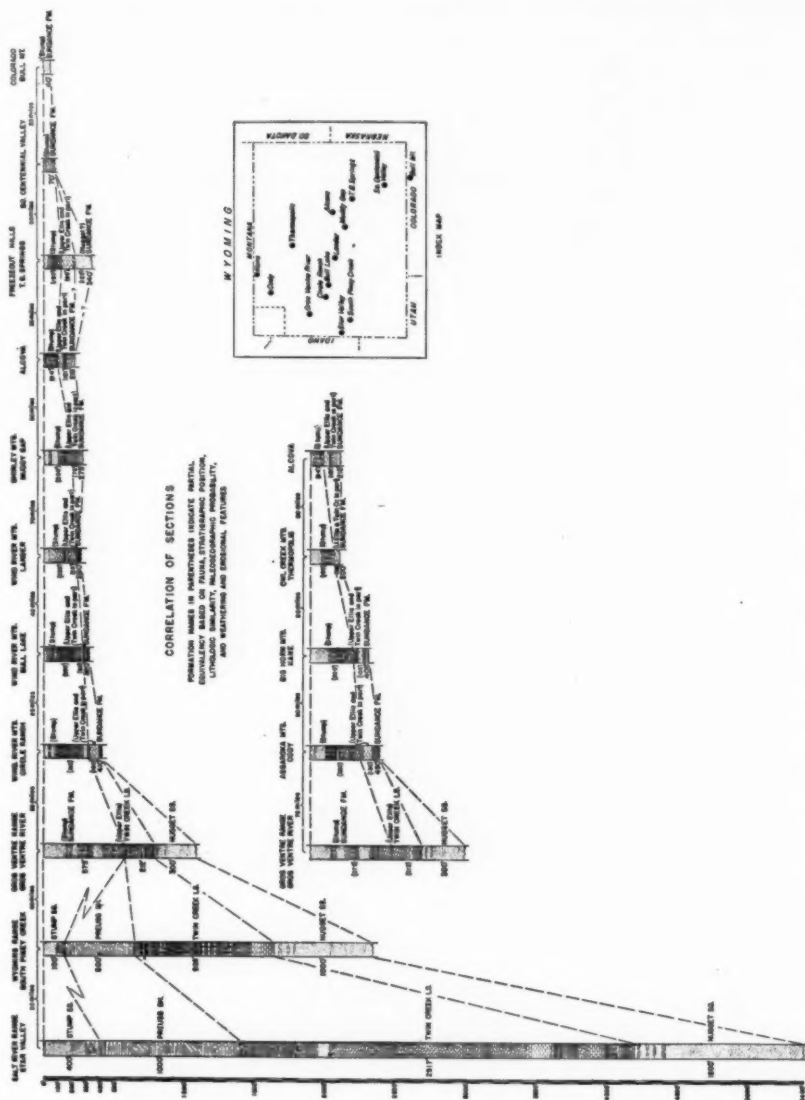


FIG. 5.—Correlation of sections from western Wyoming to north-central Colorado.

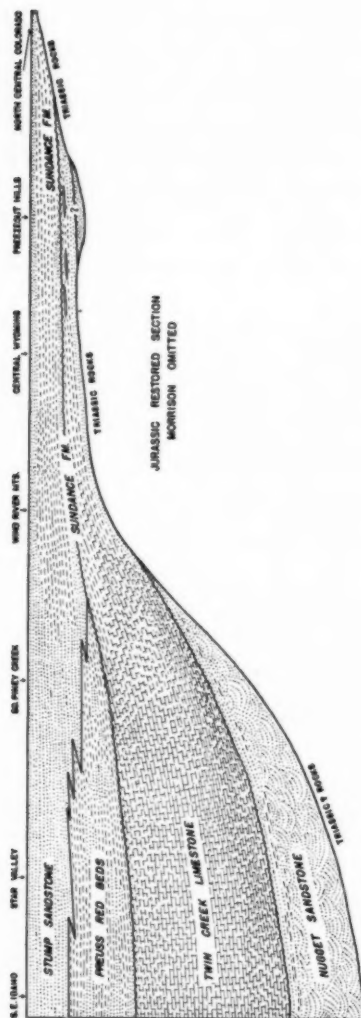


FIG. 6.—Jurassic restored section (Morrison omitted).

but it is of course impossible to present the evidence upon which various authorities have made their European assignments. Although Crickmay's assignments are seriously questioned by some, the writer has no new evidence to contradict or verify them, and because they have been made on the basis of work done chiefly in the Yellowstone National Park region, similarity of these rocks to those investigated by the writer makes the use of Crickmay's European correlation advantageous. Therefore, the correlations set forth by Crickmay⁷⁶ have, with some small changes, been used for the assignment of the Wyoming Jurassic rocks to the European type section until such time as new evidence is given which will change these correlations.

NUGGET SANDSTONE

Mansfield⁷⁷ has assigned a Jurassic age to the Nugget sandstone. He states:

Two unconformities, one of which is probably extensive, occur, . . . in rocks that lie between the Nugget and the fossiliferous rocks of the Thaynes group. For these reasons the Nugget sandstone is referred to the Jurassic.

The other reason to which Mansfield referred had to do with the Jurassic fossils collected from the Vermilion Cliff sandstone, but these have been found to be definitely younger than Nugget. No more definite age assignment can be given to the Nugget formation, in view of the present knowledge, other than that of probable Middle or Lower Jurassic age (Table XVIII).

TWIN CREEK LIMESTONE

If the writer's correlation of the Twin Creek with the Ellis formation is correct, the Twin Creek can be assigned to the Callovian of the European type section (Table XVIII). This assignment is made on the basis of the correlation of the Ellis formation with the Callovian by Crickmay.⁷⁸ Crickmay's correlation was based on a comparison of the faunas.

PREUSS AND STUMP FORMATIONS

An Argovian and Lower Kimmeridgian age can be assigned to the Preuss and Stump formations, because they are thought to be equivalent to the Sundance formation of northwestern Wyoming as defined by Crickmay,⁷⁹ to which he has given this dating.

⁷⁶ *Op. cit.*, p. 552.

⁷⁷ *Op. cit.*, p. 97.

⁷⁸ *Op. cit.*, p. 552.

⁷⁹ *Ibid.*

ELLIS FORMATION AND LOWER SUNDANCE

The Ellis formation has been assigned to the Callovian of the European type section by Crickmay,⁸⁰ and for this reason, the equivalent lower Sundance can also be assigned to the Callovian (Table XVIII).

THE UPPER SUNDANCE OF EASTERN WYOMING AND THE SUNDANCE FORMATION OF NORTHWESTERN WYOMING AS DEFINED BY CRICKMAY

Crickmay⁸¹ assigned his Sundance of northwestern Wyoming to the Argovian and Kimmeridgian of the European type section, and the upper Sundance of eastern Wyoming, if the writer's correlation is correct, is of the same age.

TABLE XVIII
CORRELATION CHART

| Germany | Utah† | Southeastern Idaho and West-Central Wyoming | Southwestern Montana and Northwestern Wyoming* | Central Wyoming | Eastern Wyoming |
|--------------------------|------------------------------|---|--|----------------------|-----------------|
| Kimmeridgian | Summerville | — ? — | — ? — | — ? — | — ? — |
| | Curtis | Stump | | | |
| Argovian | Entrada | Preuss | Sundance | U. Sundance | U. Sundance |
| | — ? — | — ? — | — ? — | — ? — | — ? — |
| Divesian | — ? — | — ? — | — ? — | — ? — | — ? — |
| | | | | | |
| Callovian | Carmel | Twin Creek | U. Ellis L. Ellis | L. Sundance | L. Sundance |
| Middle or Lower Jurassic | Navajo Kayenta Wingate | Nugget | Basal Ellis in part? | Basal Ellis in part? | |

* In the northwestern Wyoming section, the nomenclature of Crickmay has been used, dividing the section into the Ellis and Sundance formations. C. H. Crickmay, "Study in the Jurassic of Wyoming," *Bull. Geol. Soc. America*, Vol. 47 (1936), pp. 541-64.
† A. A. Baker, C. H. Dane, and J. B. Reeside, Jr., *op. cit.*, pp. 4-9.

NOMENCLATURE PROBLEMS

The problem of nomenclature involved within the Sundance formation is troublesome. If the writer's correlations are correct, and if Crickmay is correct in his interpretation of the age of the Yellowstone National Park section, the Sundance formation contains a

⁸⁰ *Ibid.*

⁸¹ *Ibid.*

hiatus which includes all of Divesian time of the European type section. The lower part of the Sundance is of Callovian age and the upper part of Argovian and Kimmeridgian age. Then also, the lower portion of the Sundance is equivalent in part to the Twin Creek and the lower Ellis as originally described,⁸² or to the Ellis of Crickmay,⁸³ and the upper portion of the Sundance is equivalent to the lower Beckwith, or the Preuss and the Stump formations, of western Wyoming, and to the upper Ellis as originally described (Sundance of Crickmay), in the northwestern portion of Wyoming. This brings up the question as to whether or not the name "Sundance" should be applied to the beds originally described as Sundance, and include the hiatus, or whether it should be split into two formations. Inasmuch as this break is within the Sundance formation as it was originally described, it is the writer's opinion that no attempt should be made at the present time to subdivide the Sundance into two formations. It is suggested, however, that until such time as it seems wise to subdivide the Sundance, the term "lower Sundance" be applied to those beds which are in part equivalent to the Twin Creek, and "upper Sundance" include all of the Sundance above this major erosion surface.

PALEOGEOGRAPHY AND LITHOGENESIS

Six blocks have been constructed to illustrate the outstanding paleogeographic features of the state of Wyoming and the immediately surrounding territory during the time of deposition of the marine Jurassic rocks (Figs. 7, 8, 9, 10, 11, and 12). Much of the apparently rapid thinning in the Jurassic rocks, particularly along the western border of the state of Wyoming, is due to the fact that the rocks have been folded and faulted since deposition, and consequently the distances between measured sections have been shortened. Therefore an attempt has been made to stretch the area out to its original form to more nearly portray the distances and conditions as they actually existed at the time of deposition. The areas which contain no state boundaries are the areas which have been stretched out (Fig. 7). The folded and faulted regions within the state correspond, in general, to these areas.

DEPOSITION OF THE NUGGET

Figure 8 shows the distribution of the Nugget sandstone as it is believed to have been at the time of the deposition. The formation was deposited by the filling of an inland basin by clastic material,

⁸² Arnold Hague, *op. cit.*

⁸³ *Op. cit.*, p. 552.

predominantly quartz sand, by fluvial and eolian agents. Much of the red material within the Nugget is probably due to the erosion and re-deposition of the underlying Triassic red beds. The region

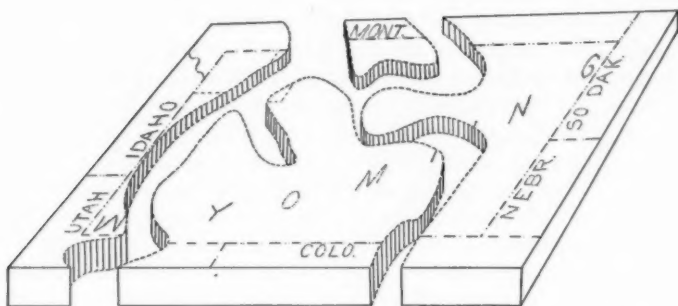


FIG. 7.—Diagrammatic illustration of the manner in which the state of Wyoming was stretched out to more closely resemble its total area during the deposition of the Jurassic rocks.

corresponding to the state of Wyoming was probably very low, and little material was supplied from an eastern direction. The main source of supply was probably a high area on the southwest, called Jurosonoria by Crickmay.⁸⁴

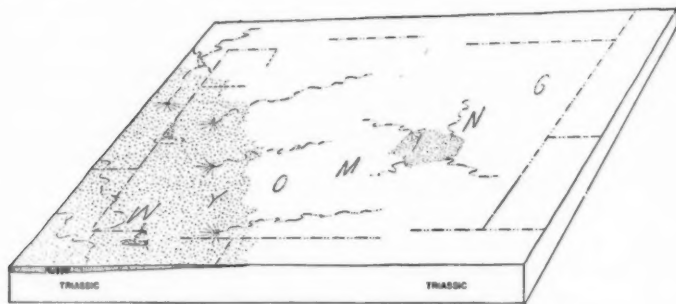


FIG. 8.—Paleogeographic map of Wyoming during Nugget deposition.

The climatic conditions which persisted at this time were probably semi-arid or arid. Plant and animal life in this region was probably very scarce.

⁸⁴ C. H. Crickmay, "Jurassic History of North America: Its Bearing on the Development of Continental Structure," *Proc. Amer. Philos. Soc.*, Vol. LXX, No. 1 (1931), p. 80.

WIDEST EXTENT OF THE TWIN CREEK SEA

Figure 9 shows the widest extent of the Twin Creek sea over the area of the state of Wyoming, in which was deposited the Twin Creek, the Ellis, and the lower Sundance. This diagram represents the region during the late Callovian or early Divesian time. Extensive shaly limestone deposition was taking place along the western margin of the state, and the source of the shaly material was undoubtedly farther west. The occurrence of lenticular red beds in the base of the Twin Creek formation is probably the result of some accumulation of clastic material from the red Triassic rocks forming the margins of the advancing sea during early Callovian time, and some of the red beds in the base of the lower Sundance formation were

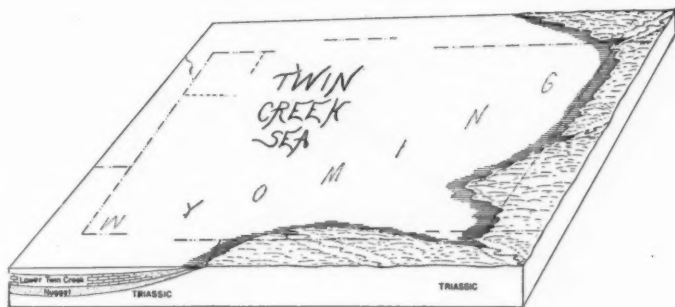


FIG. 9.—Paleogeographic map of Wyoming showing the widest extent of the Twin Creek sea.

probably derived from this same source at a later time. Some of the red beds might also have been embayment and shore facies deposits during the advance of the Twin Creek sea. The land mass on the east was very low and could not have supplied much clastic material.

A steady subsidence must have been taking place in the Cordilleran geosyncline to accommodate the great thickness of Twin Creek deposits.

Marine invertebrate life was abundant in the Twin Creek sea, and marine reptiles were also undoubtedly present, although no reptilian finds have been reported as yet, to the writer's knowledge. The climate which prevailed at this time was probably warm and humid.

The general advance of the Twin Creek sea was from the north, but its advance over the state of Wyoming was from the west or northwest.

WITHDRAWAL OF THE TWIN CREEK SEA

Figure 10 is an attempt to represent the region during the period of erosion which took place during the withdrawal of the Twin Creek sea toward the west and north. The time represented by this erosion period is some part of the early Divesian of the European type section and it is probable that at some time during the Divesian the sea was completely removed from this region. The regional drainage was probably toward the northwest, following the Twin Creek sea in its retreat. With the removal of the sea, red beds and gypsum were deposited in marginal lagoons and bays, and some interior lakes and undrained depressions were left in the central part of Wyoming. Into these depressions material was deposited. Evaporation taking place

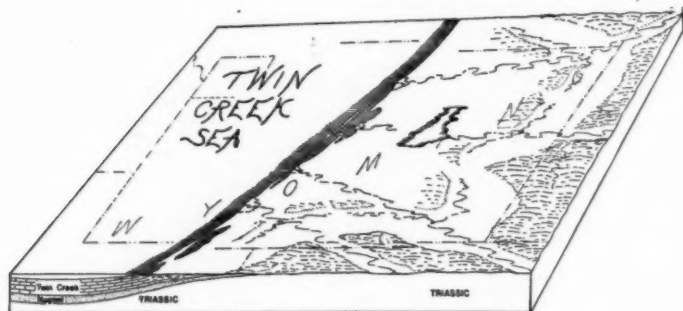


FIG. 10.—Paleogeographic map of Wyoming during the withdrawal of the Twin Creek sea.

within the inland lakes resulted in the accumulation of gypsum in the red beds. This period of erosion was not vigorous because the land was still very low. However, some of the sediment deposited from the Twin Creek sea was undoubtedly removed to the north and west by streams.

The climate during this time was probably arid, and the plant and animal life scarce.

ADVANCE OF THE LOGAN SEA

A sea again advanced from the North, following the seaway previously occupied by the Twin Creek sea, and encroached upon the area of the state of Wyoming from the west. This is known as the Logan sea. Early during the advance of the Logan sea, the Preuss formation was being deposited in the form of a great delta built out from a relatively high land mass which formed the western margin

of the sea and to which the name Jurozephyria⁸⁵ has been given. At the same time, sandstones were being deposited in the Logan sea the material being derived from streams entering the sea from the north, east and south, and also from material being re-worked by the advance of the marine waters. This sandstone has been consolidated to form the Stump formation and some of the lower sandstones in the upper Ellis or Sundance of the Yellowstone National Park region. The land mass on the east was still very low, and only a limited amount of material was derived from this direction.

The climate was probably growing more humid at this time and invertebrate and reptilian life was apparently quite plentiful in the Logan sea.

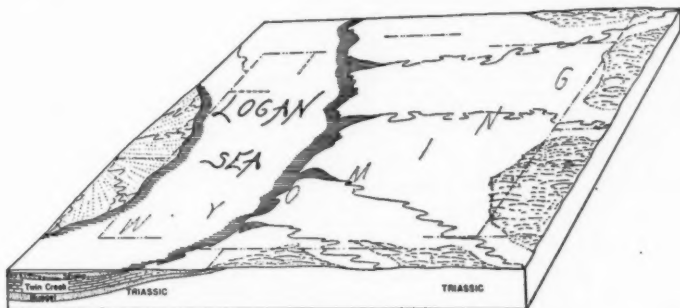


FIG. 11.—Paleogeographic map of Wyoming early during the advance of the Logan sea.

The time represented by this diagram is early Argovian of the European type section (Fig. 11).

WIDEST EXTENT OF THE LOGAN SEA

Figure 12 shows the shore line of the Logan sea at its most wide-spread extent over this region. The time represented by this diagram is late Argovian of the European time scale. In this sea, the Stump, the upper Ellis or Sundance of the northwestern portion of the state, and the upper Sundance of central and eastern Wyoming were deposited. The chief source of material was at the west, and probably most of it was derived from Jurozephyria, the high land which furnished the material for the formation of the Preuss delta. Some of the material was also derived from the eastern and northern shore lines, but these areas were very low-lying, and consequently most of the

⁸⁵ C. H. Crickmay, *op. cit.*, p. 84.

clastic material in the eastern portion of Wyoming is fine-grained shale.

The climate during this time was probably humid and warm. There was an abundance of marine invertebrate life in the Logan sea, and reptiles were apparently also fairly abundant.

PETROLEUM ASPECTS

STATISTICS

The state of Wyoming has 99 producing oil fields, and of these, 17 have production in the Sundance formation. In 38 fields the Sundance has been drilled, but has not proved productive. The Sundance is exposed at the surface in 8 fields; and in 36 fields has not been tested.

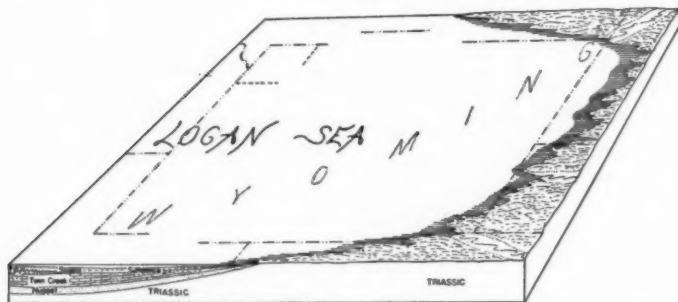


FIG. 12.—Paleogeographic map of Wyoming showing the widest extent of the Logan sea.

The information compiled for Table XIX was assembled from various sources including driller's logs and original records by Pierre LaFleiche, State Mineral Supervisor of Wyoming. Due to the difficulty in interpreting driller's logs and the difficulty of correlating the Sundance from well to well in certain fields, this information is not always accurate as to depth and thickness. Some records were lost or not available, and in those cases, the information is, of course, lacking.

LIMITATION OF KNOWN SUNDANCE PRODUCTION

Fields in which there is production of present large economic importance are limited to five counties: Sweetwater, Carbon, Albany, Natrona, and Niobrara (Table XIX). These fields all lie roughly in a belt, something more than 100 miles wide, which trends in a northeast-southwest direction across the southeastern portion of the state

STRATIGRAPHY OF SUNDANCE FORMATION 765

TABLE XIX
DATA ON SUNDANCE IN WYOMING OIL FIELDS

| County | Field | Statistics |
|----------|--------------------|--|
| Albany | Quealy | Sundance from 3,678 to 3,728 feet. Initial production 155 barrels of 32° gravity oil. One well. (Record not complete.) |
| Big Horn | Byron | Sundance from 4,000 to 4,302 feet. Oil from 4,204 to 4,245 feet. Initial production 50 barrels of 32° gravity oil. One well. |
| Carbon | Allen Lake | Sundance from 2,010 to 2,558 feet. Gas from 2,010 to 2,090 feet. Average initial production 33,000,000 cubic feet. Three wells. |
| | East Allen Lake | Sundance from 1,865 to 2,084 feet. Gas from 2,044 to 2,084 feet. Initial production 11,000,000 cubic feet. One well. |
| | Big Medicine Bow | Sundance from 5,151 to 5,400 feet. Oil and gas from 5,151 to 5,222 feet and from 5,299 to 5,400 feet. Initial production 6,000 barrels of oil and 81,000,000 cubic feet of gas. Gravity of the oil from the first sand, 70.6 (distillate), from the second sand, 63.1° A.P.I. |
| | Ferris | Sundance from 2,528 to 2,960 feet. Oil from 2,615 to 2,705 feet. Initial production 30 barrels of 32° gravity oil. Two wells. |
| | Ferris (West) | Gas in the Sundance from 2,292 to 2,296 feet. Four wells. |
| | Mahoney | Sundance from 2,410 to 3,136 feet. Gas from 2,525 to 2,925 feet. Initial production 25,000,000 cubic feet. Twenty-one wells. |
| | Rock River | Sundance from 3,1287 to 3,360 feet. Oil from 3,150 to 3,210 feet. Initial production from 200 to 1,000 barrels of 36.4° gravity oil. Ten wells. |
| Fremont | Alkali Butte | Sundance from 4,670 to 5,240 feet. Salt water from 4,290 to 4,930 feet. A showing of oil and gas at 4,925 feet. |
| Natrona | Bolton Creek | Sundance from 1,090 to 1,335 feet. Oil from 1,090 to 1,110 feet. Initial production 150 barrels of 26.9° gravity oil. Six wells. |
| | Poison Spider | Sundance from 1,160 to 1,415 feet. Oil and gas from 1,350 to 1,415 feet. Initial production 13,000,000 cubic feet of gas and 45 barrels of 21° gravity black asphalt oil. Eighteen wells. |
| | Salt Creek | Sundance from 2,425 to 2,860 feet. First sand from 2,425 to 2,525 feet, water. Second sand from 2,630 to 2,730 feet, oil (all producing wells are now in this sand). Third sand from 2,822 to 2,860 feet, oil. Initial production from 250 to 6,000 barrels of 35.7° gravity oil. There were 47 wells; now 42, of which 9 are abandoned. |
| | South Casper Creek | Depth unknown. Gas from 1,400 to 1,500 feet. Initial production 18,000,000 cubic feet. Four wells producing. |

TABLE XIX (Continued)

| County | Field | Statistics |
|------------|--------------------|---|
| Niobrara | Lance Creek | Sundance from 3,615 to 3,887 feet. Gas and black oil of 36-38° gravity from 3,645 to 3,654 feet and from 3,690 to 3,704 feet. Three wells. Green oil of 49° gravity from 3,794 to 3,819 feet and from 3,844 to 3,887 feet. Thirty-nine wells. Average initial production of green oil 2,000 barrels, black oil 500 barrels, and gas 3,000,000 cubic feet. |
| Park | Oregon Basin | Sundance from 1,810 to 2,320 feet. Gas from 2,020 to 2,100 feet. |
| Sweetwater | Lost Soldier | Sundance from 1,831? to 2,526 feet. Oil from 1,831? to 1,848 feet. Average initial production from 147 to 1,500 barrels of 28.2° gravity oil. Six wells. |
| | North Baxter Basin | Depth unknown. Gas from 3,466 to 3,473 feet. Initial production 3,500,000 cubic feet. Two wells. |

of Wyoming (Fig. 13). Sundance production farther south, in Colorado, also falls within this belt. The majority of the wells drilled in the Big Horn Basin region, northwestern Wyoming, have tested the Sundance formation, and produce from horizons below the Sundance. With the exception of one well, in the Byron field, Big Horn county, no well in the Big Horn region has yielded commercial quantities of oil or gas from the Sundance. The Byron well is small, with an initial production of 50 barrels. From Fremont county, only one field has reported a showing of oil and gas in the Sundance, and the Sundance gas production in Baxter Basin, Sweetwater County, is limited to two wells which are located on a fault block. Other Sundance tests in the Baxter Basin field have shown no production.

THEORIES ON ACCUMULATION AND DISTRIBUTION

Three theories can be cited as applicable to the method of accumulation of oil in the Sundance formation to account for the distribution of production. They are (1) the existence of certain zonal paleo-biochemical conditions during the deposition of Sundance sediments, (2) migration of oil up the initial dip of the Sundance sediments before post-Cretaceous folding, and (3) near-shore facies textural control of the reservoir qualities of the Sundance sands.

Paleo-biochemical conditions.—Trask⁸⁶ has demonstrated that the source of petroleum is controlled by the presence or absence of marine

⁸⁶ Parker D. Trask, "Origin and Environment of Source Sediments of Petroleum," *American Petroleum Institute* (1932).

organisms, and that the distribution of marine organisms depends on their physical and chemical environments. Trask also points out that the organic content of marine sediments is highest near shore and in shallow water, and, from the coast seaward, the organic content remains more or less constant for 100 miles. From 100 to 500 miles off shore the organic content diminishes rapidly, and at the 500-mile point it is present in an insignificant quantity.

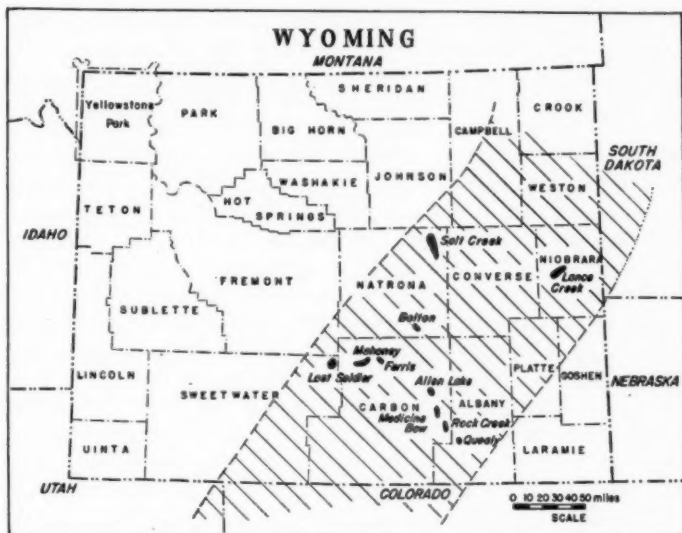


FIG. 13.—Sundance "belt of production."

The major producing Sundance fields consist of anticlinal structures lying in a belt slightly more than 100 miles broad. This belt trends along, and is parallel to, the ancient shore lines of the Twin Creek and Logan (Sundance) seas (see Figs. 9, 12, and 13). The easternmost margin of the "belt of production" lies a few miles west of the easternmost occurrence of marine Sundance. However, no favorable structure has yet been tested which involves the apex of the wedge of marine Jurassic sediments, and if such a structure were found and proved productive, the "belt of production" would extend to the shore line. The Twin Creek and Logan seas were probably shallow, and no doubt the shore line fluctuated during the deposition of

Sundance sediments, so that the zone of high concentration of organic matter was probably of unusual width. This zone necessarily advanced and retreated across the state with the transgression and regression of the seas, and fluctuated with the changing shore line. It seems logical to believe that conditions controlling the organic content of Jurassic sediments were comparable to those which control the organic content of modern sediments. If zonal bio-chemical conditions existed near shore during the deposition of Jurassic sediments, and if those conditions are responsible for the general distribution of petroleum in the Sundance formation today, the shore line during most of the time of deposition probably remained in close proximity to the shore line at the time of the most widespread inundation.

Up-dip migration.—Levorsen⁸⁷ has been a strong advocate of stratigraphic accumulation of petroleum, and has demonstrated that many of the major fields in the United States exist because of stratigraphic rather than structural traps. This theory of accumulation is applicable, with reserve, to the distribution of petroleum within the Sundance sediments. The "belt of production" trends along the "wedge edge" of the Sundance. However, as far as exploration has progressed to date, local structures within this belt have been essential for production. The Wyoming Sundance sediments, upon deposition, must have had an initial dip from the shore line on the west, and, as far as can be determined, no marked folding took place in Wyoming until late Cretaceous time. To those who advocate long-distance migration, it might seem plausible to account for the distribution of oil in the "belt of production," and the lack of Sundance oil in the northwestern part of the state, by migration up the initial dip of the sediments. It might also be pointed out that there is strong evidence of an unconformity between the lower and upper Sundance sediments, as discussed in the preceding pages of this paper, and also that the basal sand of the Sundance is one of the major producing horizons. Although there is no evidence of angular discordance between the lower and the upper Sundance, petroleum may have been formed and trapped beneath that unconformity. Strictly speaking, the distribution of petroleum within the Sundance formation requires many conditions which are not required in the "up-dip wedge-edge porosity" theory of Levorsen and others; namely, extremely long-distance migration and general concentration in a broad zone rather than in actual small stratigraphic traps. Stratigraphic traps of that type no doubt exist within the Sundance formation, and they may well con-

⁸⁷ A. I. Levorsen, "Stratigraphic Versus Structural Accumulation," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 20 (1936), pp. 521-30; and others.

tain oil in commercial quantities, but none have been discovered up to the present time.

Near-shore facies textural control.—Extensive sand analyses have not yet been completed for the Sundance sands. However, some progress is now being made by the Geological Survey of Wyoming toward that end. Due to the nature of the succession of Sundance rocks, that is, alternating carbonaceous shales and porous sandstones, and because the sands are probably coarser and more porous in the near-shore deposits, the sands of near-shore facies probably make better reservoirs for the accumulation of oil generated in, and derived from, the carbonaceous shales. If the shore line fluctuated, which seems logical, the coarser near-shore sediments would extend over a more widespread area than would be the case with a nearly stationary shore line. It is possible, therefore, that the creation of more porous reservoir rocks along the fluctuating shore line of the Twin Creek and Logan seas might exercise some control over the distribution of oil.

Flushing.—Southeastern Wyoming is, in general, an area of high hydrostatic pressures, and water flushing has probably played no small part in local accumulations of oil and in the absence of oil in certain well-defined structures. It may be that steep-sided structures are essential to hold oil in the Sundance sands, which are apparently more pervious than sands in some of the other producing formations. The Big Muddy field, Converse County, lies in the middle of the "belt of production" and is almost completely surrounded by commercial Sundance fields, yet a test to the Sundance at Big Muddy proved unproductive. The flanks of the Big Muddy structure have relatively low dips, and the hydrostatic pressure is high. The absence of Sundance oil can logically be explained as being due to flushing.

Probability of theories of accumulation.—It is probable that no one of the previously listed theories descriptive of the method of accumulation and distribution of petroleum in the Sundance formation, nor any other single method, could account for the distribution of Sundance oil. There were no doubt many unknown factors which controlled the accumulation of oil in commercial amounts. The three theories listed may have played some part. It is not the intention of the writer to advocate any theory pertaining to distribution of Sundance oil, but merely to point out the nature of the distribution and list some of the theories which seem to be suggestive. Of the three listed, the first, that of a "paleo-biochemical" control seems to the writer to be most suggestive of the cause of the type of accumulation which has been found in the Sundance.

SUMMARY

In the preparation of this paper, it has been the writer's purpose to make additional contributions toward a clearer understanding of the marine Jurassic rocks which occur within the state of Wyoming. It is the writer's belief that evidence has been shown which tends to substantiate the following correlations: 1, that the Nugget formation may be equivalent to the thick basal sandstone within the Sundance formation in the vicinity of the Freezeout Hills, southeastern Wyoming; 2, that the Twin Creek formation is in part equivalent to the Ellis formation of northwestern Wyoming, and to the lower portion of the Sundance formation in central and eastern Wyoming; 3, that there is an erosional interval within the Sundance formation, and that this erosion period corresponds with the time of withdrawal of the Twin Creek sea; 4, that the upper portion of the Sundance formation is equivalent to the Preuss and the Stump formations of western Wyoming and southeastern Idaho and to the upper portion of the Ellis formation of northwestern Wyoming, or the Sundance formation as it has been re-defined by Crickmay. In this paper, the writer has also attempted an explanation of the occurrence of red beds and gypsum within the Sundance formation. It is believed that these red beds were deposited, in part at least, in inland lakes and undrained depressions immediately after the retreat of the Twin Creek sea and during the erosion period which followed, and in part in the marginal lagoons and bays of the retreating sea. An attempt has also been made to clarify the paleogeography of this region during the time of deposition of the marine Jurassic rocks.

The economic portion of this paper is intended to point out the areas, depth, initial production, and quality of the oil from the Sundance formation. The distribution of Sundance fields is striking. The important Sundance fields lie in a broad belt which parallels the shore line of the Twin Creek and Logan (Sundance) seas. Theories which appear to be in part applicable to such an accumulation are (1) the existence of paleo-biochemical conditions associated with the shallow-water near-shore deposits which controlled the abundance of petroleum-forming organisms, (2) migration of petroleum up the initial dip of the Sundance sediments before the folding during late Cretaceous time, and (3) porosity control by the coarser-textured sandstones deposited near the shore. It is not advocated that any one, or all, of these theoretical concepts accounts for the distribution of Sundance oil; however, they may have been in some part responsible for the distribution.

ILLINOIS BASIN¹

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ABSTRACT

I. *Structural history.*—The Illinois basin is part of a larger basin which during Paleozoic time extended an unknown distance southward. The greater part of the relative uplift of the borders of the Illinois basin probably occurred at the close of the Paleozoic era (Appalachian revolution). Major and minor structures within the basin were formed at various times during the Paleozoic era; much deformation along the southern border of the basin was of post-Paleozoic age. The time of origin of the more important known structures in the basin is discussed.

II. *Exploration for oil.*—The history of oil exploration in Illinois is briefly reviewed with special attention to the great southeastern Illinois field which ranks sixth in total production to date in the United States. During most of the 32 years following discovery of this field there has been little systematic exploration for oil in Illinois, but this has been due in large measure to the belief that oil production is probable only around the rims and not in the central portions of large structural basins. Discovery of the Mt. Pleasant field in Michigan and numerous fields in West Texas and elsewhere has upset this belief, so that now many geologists and oil executives favor careful exploration for oil throughout the areas of large structural basins. Possible oil-producing formations in the Illinois basin and structural trends in the basin with relation to oil possibilities are discussed.

Since 1934 the central part of the basin has been explored scientifically by both geological and geophysical methods. The first discoveries following the recent activity have come in 1937; three new oil wells, all located on the basis of seismograph surveys, and two of which are in the deep basin area, appear to be the beginning of a new period of development.

For about a year and a half an intense leasing campaign has been in progress in the Illinois basin. This has been participated in by about ten major companies and by many smaller companies and individuals. Most of the major companies are depending principally upon seismograph surveys to guide their exploratory drilling. The Illinois basin area is now looked on by the industry as one of the country's most promising areas, and accordingly a report on the territory is appropriate in a program which seeks to cover current activity.

The writers' purpose in this paper is to present a brief summary of the geologic history of the Illinois basin with special reference to structure and to discuss the application of geological knowledge to exploration for oil in the territory.

¹ Presented before the Association at Los Angeles, March 19, 1937. Published with the permission of the chief, Illinois State Geological Survey.

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PART I—STRUCTURAL HISTORY

By J. MARVIN WELLER

Most of the State of Illinois lies within the great structural basin that is included between the Cincinnati arch on the east, the Wiscon-

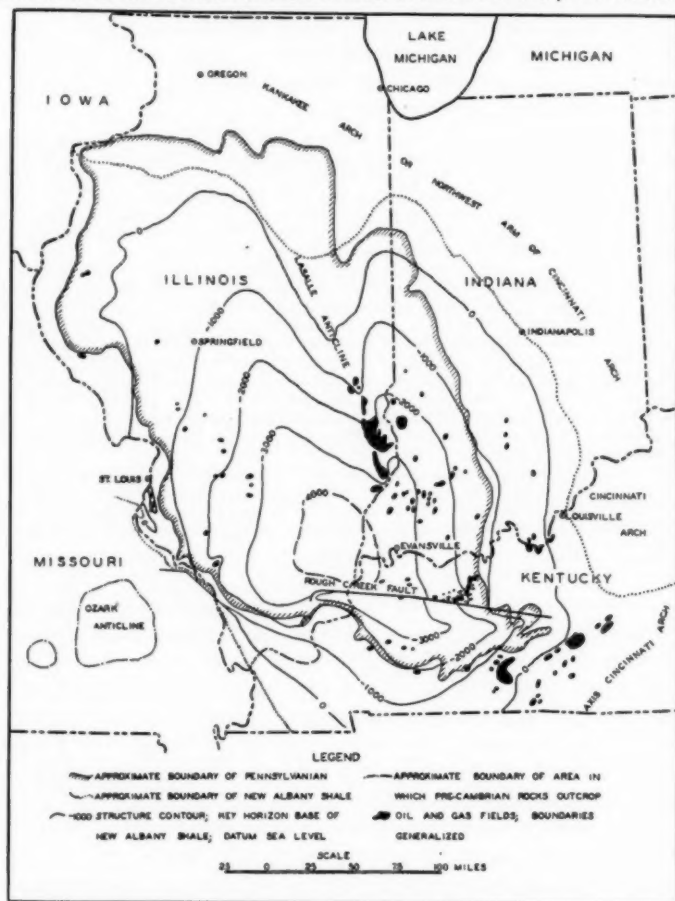


FIG. 1.—Map of Eastern Interior coal basin, showing principal tectonic features, oil and gas fields, and subsurface structure on base of New Albany shale. (From *Problems of Petroleum Geology, a Symposium*, American Association of Petroleum Geologists, Tulsa, Oklahoma, 1934, p. 559.)

sin uplands on the north, and the Mississippi arch and the Ozark region on the west (Fig. 1). This basin includes adjacent parts of

southwestern Indiana and western Kentucky. Pennsylvanian rocks occur at the surface or immediately below the glacial drift throughout most of this area, but beneath them there exists a thick and fairly complete succession of the older Paleozoic systems (Fig. 3).

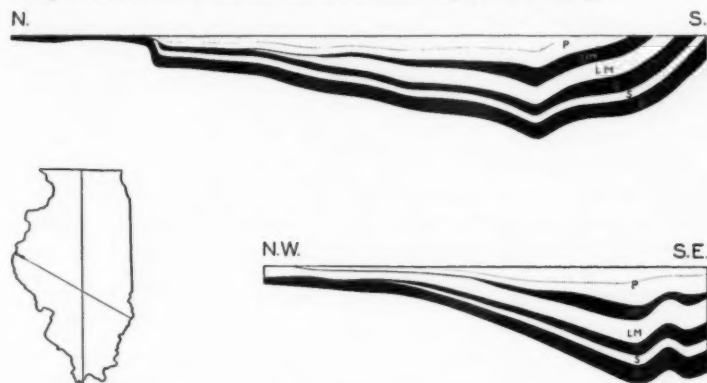


FIG. 2.—Cross sections of Illinois basin. P, Pennsylvanian (dotted line shows position of coal No. 6); LM, Lower Mississippian; S, Silurian; O, Ordovician. (From "Geology and Oil Possibilities of the Illinois basin," *Illinois State Geol. Survey Illinois Petroleum No. 27*, July 11, 1936, p. 5.)

The Ozark region and the Wisconsin uplands are relatively stable areas which have not been subjected to notable depression or deeply buried by sediments since pre-Cambrian time. The Cincinnati arch is believed to have been in existence during the Ordovician period and may reflect conditions in the basement rocks dating back much farther. The monocline that bounds the Illinois basin on the south, however, is of much later origin and probably came into existence during the Appalachian uplift.

Well data indicate, so far as they are available, that practically all of the systems thicken notably inward and southward or southeastward in the basin (Fig. 2). This is particularly true of the Devonian system, which, with the exception of the ubiquitous New Albany shale and its equivalents, is poorly represented, or possibly absent locally, except in the southern part. If the results of the pre-Pennsylvanian unconformity are ignored for the moment, the thinnest and most incomplete post-St. Peter section occurs in western Illinois and northeastern Missouri on and adjacent to the Mississippi arch that connects the Ozark region with the Wisconsin uplands and separates the Illinois basin from the northeastern extension of the Mid-Continent (Western Interior) basin.

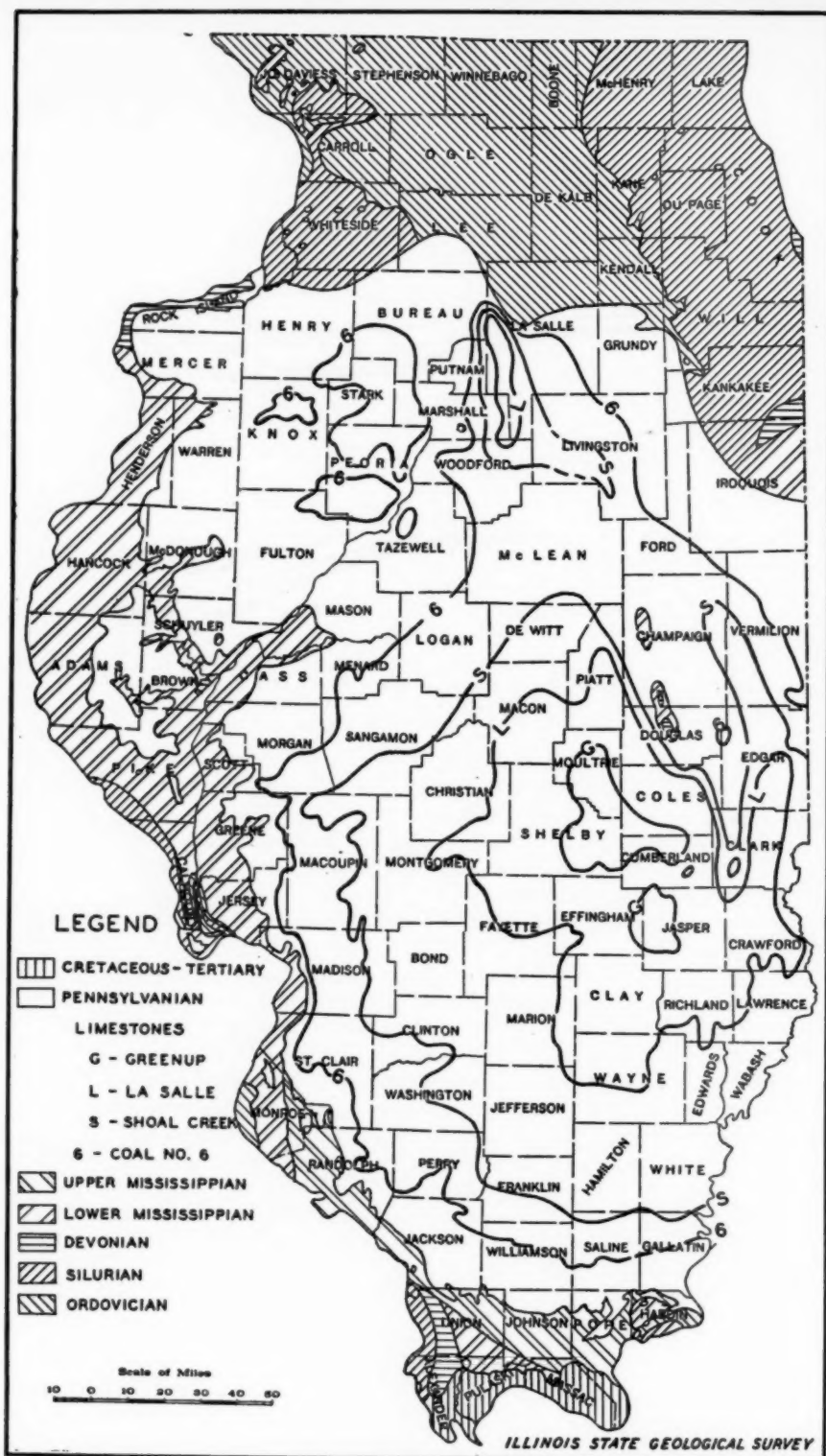


FIG. 3.—Areal geology of Illinois (modified after Fig. 14, p. 128, *Illinois State Geol. Survey Bulletin 61*, "Rock Wool").

The southward thickening of all of the Paleozoic systems above the Cambrian (which has not been penetrated in wells) continues to the extreme southern limit of the Illinois basin, where the Paleozoic beds pass beneath the younger sediments of the Mississippi embayment. This fact, together with the known age of the uplift which bounds the basin on the south, is proof that the Illinois basin as it exists today is only the northern part of a larger basin which during Paleozoic time extended an unknown distance toward the south along the present course of the Mississippi valley. It is probable that during Paleozoic time the Illinois basin communicated freely with the Arkansas valley trough, although marine connections were established frequently and for long periods of time across the Cincinnati arch toward the east and across the Mississippi arch and even the Ozark region toward the west. It is probable that the greatest amount of uplift of all the borders of the Illinois basin (or the greatest depression of the basin itself) that occurred at any single time was accomplished at the end of the Paleozoic era. In other words, the major part of the gross structure of the Eastern Interior United States, although previously determined and long in existence on a smaller scale, dates from the Appalachian revolution.

The earlier structural history of the Illinois basin is not well known. Numerous unconformities occur between the formations, but except where they obviously represent important erosional intervals, their significance is not apparent. The oldest known erosional unconformity occurs at the base of the St. Peter sandstone in north-central Illinois, but this horizon has not been penetrated by the drill elsewhere in the state except along the western border. It appears to record, however, uplift of the Kankakee arch (west branch of Cincinnati arch) in Ordovician time.

Considerable relief was developed by erosion of the Maquoketa shale in northern Illinois at the close of the Ordovician, but this erosion, so far as is known, was unrelated to structure.

During Lower and Middle Devonian times a structural basin extended across southern Illinois into southwestern Missouri, while, probably contemporaneously, a domal uplift occurred in western Illinois and northeastern Missouri. A great thickness of sediments accumulated in the basin, whereas the dome was eroded through the Silurian and Maquoketa into the Galena formation. The Upper Devonian sediments cover the Middle Devonian in the south and overlap with variable thickness an uneven erosion surface in central and western Illinois. The Colmar oil field is a minor structure on the northeast flank of the dome, where local sedimentary conditions produced a concentration of Upper Devonian sand.

Later erosional intervals and related structural movements are best exhibited upon the flanks of the Ozarks. In Ste. Genevieve County, Missouri, post-Middle Devonian faulting occurred, followed by peneplanation and overlap by Mississippian formations. This system of faults probably extends beneath these beds into southwestern Illinois, but has not been accurately located. Disturbances of similar age are unknown elsewhere in the basin.

Overlap of New Albany (so-called Chattanooga) shale of Upper Devonian or Lower Mississippian age onto Ordovician limestones occurs well up on the Cincinnati arch in southern Kentucky and somewhat similar overlap of Bushberg sandstone (basal Kinderhook) occurs in northeastern Missouri.

Conspicuous overlap of the Fern Glen (basal Osage) onto Maquoketa shale occurs in Monroe County, Illinois, and similar but less extensive erosion preceded deposition of the Sedalia (= Fern Glen) limestone farther north in the Mississippi valley. Although the total absence of Silurian, Devonian, and Lower Mississippian from outcrops in Monroe County may be the result of more than one period of erosion, it at least suggests that the Valmeyer and probably also the Waterloo anticlines were in existence before the beginning of middle Mississippian time.

The existence of a basal conglomerate in the Ste. Genevieve formation containing silicified Middle Devonian fossils in Ste. Genevieve County, Missouri, records uplift and erosion of the Ozarks after St. Louis time. In the Ohio valley, however, the Ste. Genevieve appears to succeed the St. Louis with perfect conformity.

A widespread unconformity separating the Ste. Genevieve limestone from the overlying Chester series is recognized in outcrops around the margins of the basin. Erosion at this horizon, however, was relatively unimportant except in Monroe County, where the Ste. Genevieve is overlapped and the Chester locally rests on the St. Louis limestone. Apparently renewed folding of the Valmeyer and Waterloo anticlines, followed by erosion, occurred at this time. In the same area the Lower Chester beds exhibit definite overlap relations with the Renault formation, extending beyond the limits of the basal Aux Vases sandstone to rest upon the Middle Mississippian limestones. Possibly the porosity of the McClosky "sand" (limestone) of Lawrence County is related to this unconformity.

By far the most important unconformity of the Illinois basin occurs beneath the Pennsylvanian (Fig. 2). From south to north the Pennsylvanian overlaps a stratigraphic section 3,000 feet thick from the top of the Chester to the St. Peter sandstone. For the most part

this unconformity is known to possess little local relief, although in Edmonson County, Kentucky, a channel 300 feet deep was eroded in Chester strata. In Monroe County, Illinois, Chester hills of moderate height are surrounded by Pennsylvanian beds and locally are exposed as inliers, and similar hills of St. Louis limestone and Warsaw formation occur in Fulton County. What may be basal Pennsylvanian strata preserved in sink holes are known in Calhoun and Pike counties. Thick deposits of glacial drift which form the surface throughout most of Illinois, however, make the recognition of such features difficult except in especially favorably situated localities.

Although the absence of Silurian, Devonian, and Mississippian strata beneath the Pennsylvanian in northern Illinois may be the result of more than one erosional interval, and most of the Devonian and the Chester may never have been deposited in this area, still it is certain that extensive erosion did occur in late Mississippian or early Pennsylvanian time, because remnants of Upper Devonian shale are preserved in crevices in the Silurian dolomite of the Chicago region and because cherts of Osage age have been recognized in glacial gravel deposits of northern Illinois, demonstrating that these strata were originally present farther north, well beyond their present boundaries.

Important folding likewise occurred at the close of the Mississippian period. All of the borders of the Illinois basin were upraised. Folding occurred along the Cincinnati arch, and Chester strata which originally spanned this structure in Kentucky were completely removed so that outliers of the Pennsylvanian are now found on strata at least as old as the St. Louis limestone. Wisconsin and northern Illinois were upraised and, as already mentioned, erosion cut deeply into the Ordovician. The Ozark region was also lifted; its Mississippian cover, which consisted at least of the Osage formations (and possibly also older beds) was completely stripped off so that Pennsylvanian outliers now rest upon Ordovician strata. In this same region pronounced karst topography was either developed or an old karst surface was re-exposed and accentuated and Pennsylvanian sediments and coals were deposited in sink holes in which they are preserved to the present time. Pennsylvanian clays and sands are likewise present in solution channels and caverns in the Silurian formations in northwestern and northeastern Illinois and in Mississippian limestones in Missouri and western Illinois.

Within the basin preëxisting structures such as the Valmeyer and Waterloo anticlines were accentuated (Fig. 4). In addition other structures not known to have been previously in existence were produced. The most important of these is the La Salle anticline (Fig. 4),

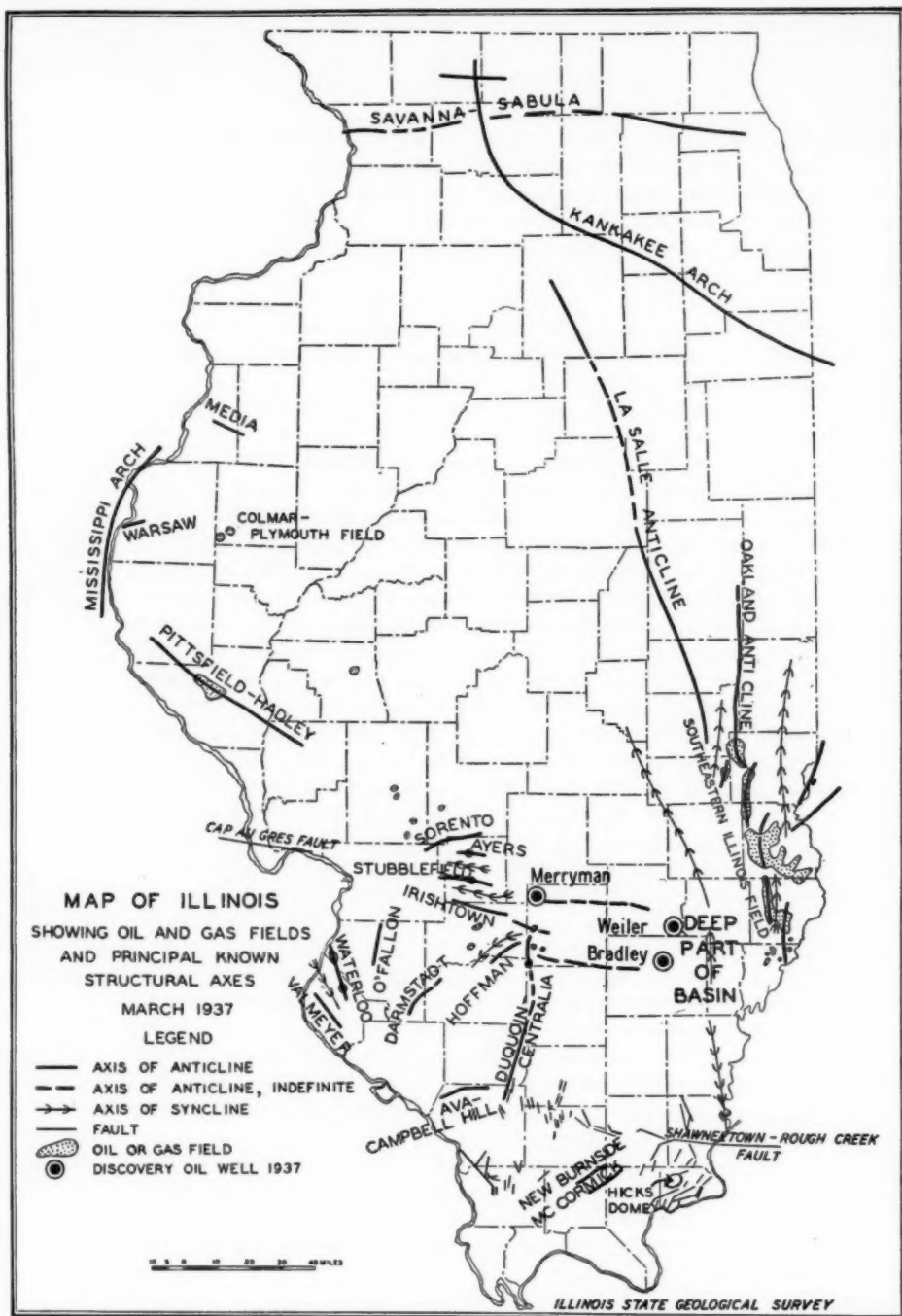


FIG. 4.—Map of Illinois showing oil and gas fields, principal known structural axes, and discovery oil wells, January-March, 1937.

which detaches itself from the Kankakee arch in Lee County and plunges east of south to the Wabash River a short distance below Vincennes. Another conspicuous structure that appears to have originated at this time is the Cap-au-Gres fault (Fig. 4) which, in Illinois at least, is mainly a sharp, very steeply dipping monocline modified by subordinate small *en échelon* faults. Probably the Pittsfield-Hadley anticline in Pike County also was formed at the close of the Mississippian period, although the absence of overlapping Pennsylvanian beds on the crest of the structure renders this dating somewhat uncertain. Faulting on a small scale occurred in Union County, Illinois, and in Grayson County, Kentucky.

It is possible that other known folded structures which exist farther within the borders of the basin were initiated, or, if previously in existence, were accentuated at this time, but subsurface data are for the most part too incomplete to make this interpretation positive.

After the epoch of disturbance which produced these uplifts, smaller folds, and displacements, erosion reduced their summits in some degree and weathering locally rendered limestones porous, as on the La Salle anticline in Clark County and near Jacksonville in Morgan County.

Deepening of the basin and accentuation of the smaller structures continued in varying degree throughout the Pennsylvanian period. The Pennsylvanian system shows greater variation of thickness of sediment from place to place within the basin than the other systems. This is particularly true of the beds which underlie coal No. 2 although it also holds to a lesser degree for strata above this coal, to the top of the system as it is developed in the Illinois basin. For example, a section 700 or more feet thick in southern Illinois and western Kentucky is reduced to a few feet in the vicinity of St. Louis and northward along the Mississippi valley and on the La Salle anticline in the upper Illinois valley. This thinning does not represent overlap to any great extent, but is mainly the result of thinning and wedging out of individual members and of transition from thick layers of clastic to thin deposits of much finer materials. Similar although probably less marked thinning, mainly of the Lower Pennsylvanian section, also occurred upon the flanks of structures within the basin, as for example along the La Salle anticline, although subsurface data are too meager to reveal details.

Differential subsidence within the basin appears to have produced at least one new structural axis, the DuQuoin anticline (Fig. 4). This structure is not a continuous anticline but is more accurately described as a steep monocline broken by subordinate faults and termi-

nating above in a broad terrace which is locally domed. It separates an area of thin Pennsylvanian sediments on the west from an area with a much thicker section of equivalent beds on the east. It was uplifted more or less gradually and continuously throughout Lower and Middle Pennsylvanian time.

The last important structural readjustment of the Illinois basin occurred, as already stated, at the close of the Paleozoic era or possibly early in the Mesozoic. The youngest Pennsylvanian beds present in the basin were involved in this disturbance and the region was subsequently peneplaned and overlapped from the south by late Cretaceous sediments of the Mississippi Embayment. Subsequently the embayment area, including the southern tip of Illinois and the western tip of Kentucky, was depressed, but this movement does not seem to have involved any portion of the Illinois basin except its extreme southwestern margin.

The most conspicuous result of the post-Pennsylvanian disturbance was the separation of the Illinois basin from its original southward continuation, which was accomplished by the development of a northeastward dipping monocline in part complexly faulted. In the Illinois-western Kentucky fluorspar district, which includes Hardin and Pope counties, Illinois, and Crittenden, Livingston, and adjacent counties in Kentucky, faulting is dominantly of the normal type, with displacements attaining a maximum of about 2,000 feet. In Illinois the major faults extend northeast-southwest, but in Kentucky their direction gradually swings around to nearly east and west. They appear to radiate outward in these directions from a focus beneath the embayment deposits of western Kentucky. Numerous cross faults extend in all directions between the major displacements to produce an extremely complex mosaic pattern. The statement that these faults are of the normal type, does not, however, describe them adequately. Slickensides demonstrate that movements possessed important horizontal components and displacement along some faults appears to have taken place at different angles at different times. It is even probable that complete reversal of movement occurred at some places. The New Madrid earthquake almost certainly resulted from a minor disturbance in this area and every year mild tremors are reported that appear to originate here.

North of the fluorspar district and extending in an east-west direction is a complex series of ramifying faults known as the Rough Creek fault zone (Fig. 1) in western Kentucky. It decreases in importance toward the east, but appears to cross the Cincinnati arch and connect with the Irvine-Paint Creek disturbance of eastern Kentucky

and the Warfield and Chestnut Ridge anticlines of West Virginia and Pennsylvania. Toward the west, it crosses the Ohio River at Shawneetown and continues as the Shawneetown fault or faults, crosses Gallatin County, swings southward and plays out or passes into some of the previously mentioned northeast-southwest faults of Pope County.

The Rough Creek fault zone has evidently been produced by compressional forces acting from the south. This is demonstrated by the steep dips and folds that occur along this zone and the presence in it, as in Webster County, Kentucky, of areas of crumpled Chester sediments surrounded on all sides by fairly high Pennsylvanian beds. The deepest part of the western Kentucky coal field was probably produced by these same compressive forces much as foredeeps are developed adjacent to some young and rising continental coasts.

In Union County, Illinois, is the beginning of another system of faults which develops parallel to the strike on the rapidly steepening monocline and extends northwestward, crossing the Mississippi River into Missouri near Grand Tower. These faults likewise have resulted from compression, which in this case came from the southwest. Upthrow is toward the southwest and is associated with steeply dipping, vertical and even locally overturned beds.

In the fluorspar district of Illinois and Kentucky and in western Ste. Genevieve County, Missouri, also in the southern Illinois coal-mining district, are numerous small intrusions of basic igneous rock. In the fluorspar district, dikes are most common, but sills and plugs also occur and there is one locality that appears to mark an explosion vent. Hicks dome (Fig. 4), which is the outstanding structural feature of Hardin County, is believed to have been produced by an intrusion possibly of a laccolithic type. In Missouri,⁴ dikes are uncommon and most of the intrusions are small plugs. There are also numerous small structures that appear to be explosion vents that were never filled by magma but into which fragments of overlying rocks fell. They are present in a Cambrian terrain and are marked by erratic boulders, including fossiliferous Middle Devonian limestone, which at present occurs in place only down-stream 20 miles away, with which are associated fragments of biotite.

Preexisting structures were also accentuated by the post-Pennsylvanian disturbances. These include the Valmeyer and Waterloo anticlines, the Cap-au-Gres fault, and the La Salle anticline from La Salle to Clark counties. Some of the minor features of the latter structure were also accentuated at this time, for example the Martinsville dome,

⁴ George W. Rust, "Preliminary Notes on Explosive Volcanism in Southeastern Missouri," *Jour. Geol.*, Vol. XLV, No. 1 (1937), pp. 48-75.

which is outlined by comparatively steep dips and concentric outcrops of the exposed Pennsylvanian beds.

In addition there are localities within the Illinois basin where the surface structure in Pennsylvanian beds suggests more important structure in underlying formations such as those recently described in Clay and Marion counties.⁵

PART II—EXPLORATION FOR OIL

By ALFRED H. BELL

The history of exploration for oil in Illinois may be divided into three periods: (1) prior to 1905, the year production began in the Southeastern Illinois field, (2) 1905-1934, the year in which the recent activity in the deep-basin area began, and (3) 1934 to the present. During the first of these periods there was only small commercial production of oil, beginning with the discovery of the Litchfield pool in 1886.

The second period began with the discovery of the Southeastern Illinois field, one of the nation's major oil fields, which reached a production peak a few years later of nearly 100,000 barrels per day and which has produced to date more than 415 million barrels of oil from 92,000 acres. The 5-year period, 1906-1910, was marked by intensive drilling, including many scattered wildcat wells. Subsequently interest shifted to new major fields in the Mid-Continent and exploratory drilling in Illinois tapered off, reaching a low point in 1934 when only 26 wells were drilled in the whole state.

The second period saw the development of numerous oil and gas fields around the margins of the basin, for example the Sandoval field (Marion County) in 1908, the Carlyle field (Clinton County) in 1911, the Colmar-Plymouth field (McDonough and Hancock counties) in 1914, and the Dupo field (St. Clair County) in 1928. However, an area of 10,000 square miles in the central portion of the basin remained undrilled except for scattered wildcats (Fig. 5).

Under the prevalent theory of oil migration this whole area was considered unfavorable. Detailed structural conditions were practically unknown. With the discovery of the Mount Pleasant field in 1928 in the very center of the Michigan basin, it became evident that the central portion of the Illinois basin could not be dismissed from consideration as a possible source of oil. If favorable local structures

⁵ J. M. Weller and A. H. Bell, "Geology and Oil and Gas Possibilities of Parts of Marion and Clay Counties, with Discussion of the Central Portion of the Illinois Basin," *Illinois State Geol. Survey Rept. Investigations No. 40* (1936).

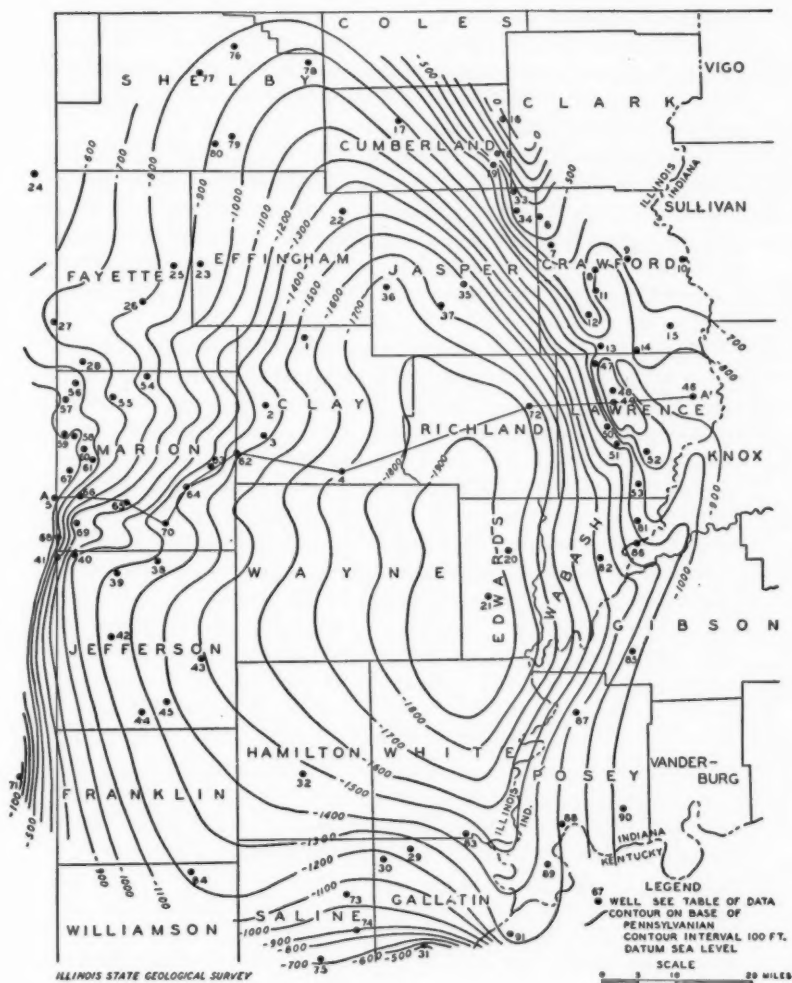


FIG. 5.—Central portion of the Illinois basin; subsurface contour map on the base of the Pennsylvanian system, a surface of unconformity. (Fig. 2, *Illinois Geological Survey Report of Investigations No. 40*, 1936.)

exist in this territory, some of them should prove productive.⁶ The important question then became how to find the areas of favorable structure. Most of Illinois is covered by glacial drift of such thickness that the bed rock and its structure is largely obscured. There appeared to be an excellent opportunity for the use of geophysical methods of exploration, such as the seismograph.

State-wide studies of Pennsylvanian stratigraphy by J. M. Weller, H. R. Wanless and others during a period of 10 years revealed that correlations of outcropping strata could be made in some areas with sufficient assurance to make possible the mapping of structure. Elevations of the outcrops in such an area were determined in the summer of 1935 and the results of this work were published March 1, 1936.⁷

During 1934, detailed studies of surface geology in the basin were begun by the Carter Oil Company, initiating the present period of activity by oil companies. Several large blocks of acreage were leased by that company in the fall of 1935, after two seasons of field work. At the same time the Pure Oil Company began seismograph work in the deepest part of the basin, and the Texas Company and the Shell Petroleum Corporation began studies of surface and subsurface geology. Ever since the beginning of 1936 the number of companies interested in the area has been increasing. During most of 1936 the number of seismograph parties active in the area has varied from 6 to 8 and during the early part of 1937 as many as 11 were active at one time. At the present writing (March, 1937), 9 seismograph parties are operating in Illinois and 2 in the adjacent part of southwestern Indiana.

RECENT NEW DISCOVERIES

The first successes in the discovery of new oil resulting from the recent activity have come since the beginning of 1937. It is a remarkable fact that the first three wells in Illinois located on the basis of seismograph surveys have all discovered oil in commercial quantities. In view of the fact that sporadic wildcat drilling, located without any scientific basis, had been going on in the Illinois basin for at least thirty years without discovering new oil fields, the recent successes surely demonstrate the value of scientific methods in exploration for oil in this region.

⁶ The possibilities of oil in the deeper part of the basin were discussed by the writer in a paper given before the Illinois Academy of Science in May, 1930.

A. H. Bell, "The Relation of Geology to the Development of the Petroleum Industry in Illinois," *Trans. Ill. Acad. Science*, Vol. 23, No. 3 (March, 1931), pp. 367-70.

⁷ J. M. Weller and A. H. Bell, "Geology and Oil and Gas Possibilities of Parts of Marion and Clay Counties, with Discussion of the Central Portion of the Illinois Basin," *Illinois State Geol. Survey Rept. of Investigations No. 40* (1936).

The first of the new wells to strike oil was the Adams Louisiana Oil Company's Glenn Merryman No. 1, center SE. $\frac{1}{4}$, SW. $\frac{1}{4}$, Sec. 21, T. 4 N., R. 1 E., Marion County, Illinois, completed January 27, 1937, total depth 1,418 feet. Oil was found in the Benoist sand (Chester series, Upper Mississippian), the top of the sand being at a depth of 1,391 feet. The sand was shot with 10 quarts of nitroglycerine in the lower 10 feet, January 26, 1937. After the shot and before cleaning out, the well flowed 86½ barrels of 38° A.P.I. oil through a ½-inch choke. In the first test after cleaning out, the well flowed 52 barrels of oil through a ½-inch choke. The well is still flowing; the daily production has declined to approximately 40 barrels.

Although the seismograph was used to determine the structure of the deeper horizons, the Merryman well is located on a structural high on coal No. 6 which was mapped in Illinois Geological Survey Bulletin 16.⁸ A number of new locations have been made in the vicinity of the Merryman well, and at the present time (March, 1937), a second well is about due to reach the sand. The Merryman well is within ½ mile of the village of Patoka and the new field is called the Patoka field. The nearest old production is the Sandoval field, 8 miles to the south (Fig. 4).

On February 26, the Pure Oil Company's Weiler well No. 1, SE. $\frac{1}{4}$, SW. $\frac{1}{4}$, SE. $\frac{1}{4}$, Sec. 33, T. 3 N., R. 8 E., Clay County, struck oil of 37° A.P.I. gravity in the Cypress sandstone (Chester series) at a depth of approximately 2,600 feet. A pumping test has recently been made, results of which are not yet available. The company intends to drill the well deeper.

On March 4, the Pure Oil Company's George Bradley well No. 1, SW. $\frac{1}{4}$, SW. $\frac{1}{4}$, NW. $\frac{1}{4}$, Sec. 26, T. 1 N., R. 7 E., Wayne County, struck oil at the approximate depth of 2,970 feet. The producing horizon is possibly the McClosky "sand" (Ste. Genevieve formation, Lower Mississippian series), or it may be a basal Chester sand. The well is reported to be flowing and is producing a considerable amount of gas with the oil.

The discovery of oil at the Weiler and Bradley wells is of special interest because of their location near the deepest part of the Illinois structural basin and their distance of 30 to 40 miles from the nearest previous production on the east and on the west. It considerably enhances our estimation of the possibilities for important new oil reserves in the deep basin area. To all of the companies who at great expense have been conducting seismograph surveys during the past

⁸ R. S. Blatchley, "Oil Resources of Illinois," *Illinois State Geol. Survey Bull.* 16 (1910), pp. 42-176, Pl. XIV, p. 142.

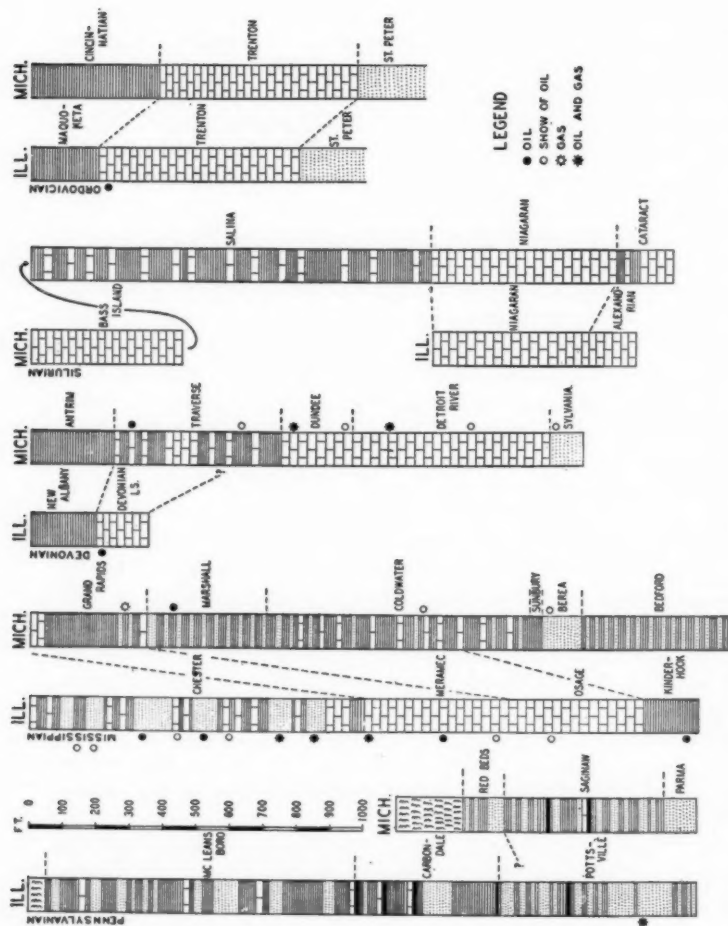


FIG. 6.—Generalized columnar sections for Illinois and Michigan basins showing principal horizons of oil and gas production. (From "Geology and Oil Possibilities of the Illinois Basin," *Illinois State Geol. Survey Illinois Petroleum No. 27*, July 11, 1936, p. 7.)

year and a half the recent successes demonstrating the utility of the method in this area must surely be gratifying. Of course only time will reveal whether the quantities of oil produced in the newly discovered fields will ultimately yield a profit on the investment.

POSSIBLE PRODUCING HORIZONS

A stratigraphic column for Illinois and for Michigan, showing the principal producing horizons in each state is shown in Figure 6.

Based on past experience, the relative order of importance of possible producing formations is as follows.

1. Pennsylvanian sands, mostly of lenticular form, and in part of the shoestring type.
2. Chester (Upper Mississippian) sands, productive on anticlines and domes.
3. Lower Mississippian limestones, productive on large closed structures; the distribution of production controlled in part by porosity which may or may not be related to an overlying unconformity.
4. Devonian limestone; small production on some closed structures.
5. Trenton limestone; production confined to high parts of large structural closures.
6. St. Peter; no production to date and no well authenticated oil showings in Illinois; contains fresh water in northern Illinois and salt water where drilled (3 wells to date) in southeastern Illinois.

The average depth of drilling for oil and gas has shown a tendency to increase progressively since the industry began. This is due in part to exhaustion of shallower oil reserves and in part to improved technique of drilling and of lifting the oil to the surface. To many persons familiar with the current drilling operations in California and the Gulf Coast where great depths prevail in many fields, it may seem strange that any considerable amount of oil at shallow depths remains undiscovered. Many from the Mid-Continent area think that the St. Peter sandstone, considered as correlative with the "Wilcox" sand, is the most important prospective oil horizon in Illinois. Little is actually known of St. Peter possibilities in the basin area, where it lies at depths probably as great as 7,000 to 8,000 feet. Experience, however, seems to indicate better prospects in shallower formations.

Although exact figures are not available, the following is an approximate division of the total oil production to 1936 from the various geologic systems in Illinois.

| <i>Geologic System</i> | <i>Per Cent of Total Production to 1936</i> |
|-------------------------|---|
| Pennsylvanian | 60± |
| Mississippian | 39± |
| Devonian and Ordovician | 1— |
| Silurian | 0 |

The location of the oil and gas fields and of the new discoveries with respect to known structural trends is shown in Figure 4. The dashed east-west axes west of the Weiler and Bradley wells are in accordance with a subsurface contour map on the base of the Pennsylvanian (Fig. 5) prepared by the writer.⁹ No doubt the seismograph has revealed the trends of the structures on which these wells are located, but the information is not available at this time.

The new data now being obtained from drilling will doubtless give new light on the subsurface stratigraphy and structure of the Illinois basin. This will unquestionably be of value in guiding future drilling and if properly used it will minimize expenditures for needless drilling in unpromising areas.

⁹ J. M. Weller and A. H. Bell, "Geology and Oil and Gas Possibilities of Parts of Marion and Clay Counties with Discussion of the Central Portion of the Illinois Basin," *Illinois State Geol. Survey Rept. Investigations No. 40* (1936), Fig. 2, p. 14.

USE OF TEMPERATURE MEASUREMENTS FOR CEMENTATION CONTROL AND CORRELATIONS IN DRILL HOLES¹

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ABSTRACT

After comparing the early and the modern methods of temperature investigations in drill holes, the authors review briefly the main applications of these measurements to oil wells.

The possibilities and limitations of two specific techniques are discussed, namely: location of cemented zones, and correlation between different wells.

The location of the cement behind the casing by thermometric measurements is quite feasible and commercially successful, provided such measurements are made immediately after the completion of the cementing job, and preferably before any circulation of mud has taken place.

Although temperature measurements can not be expected to replace the electrical methods of logging wells, they may be used successfully in certain instances to correlate wells already cased where no other method of investigation can be applied.

INTRODUCTION

The study of heat flow within the outer crust of the earth has been carried on more or less intermittently for more than a century. This study has, in general, been limited to two fields, (1) determination of geothermal gradients, that is, the increase of temperature with depth, and (2) determination, in laboratories, of the thermal conductivity of samples obtained by core drilling or mining.

A very considerable amount of information has been thus accumulated during recent years on geothermal gradients. Originally, the temperatures for the determination of geothermal gradients were taken in mine shafts, but the wells drilled for oil, reaching to successively greater depths, have offered a better opportunity for measuring the temperature of the deep formations. These measurements, combined with the subsurface studies developed by petroleum geologists, have shown the importance of the relations between the geothermal gradient and geologic structure.

In 1926, the American Petroleum Institute inaugurated the first

¹ Read before the Association at Los Angeles, March 18, 1937.

² Schlumberger Well Surveying Corporation. The writers wish to acknowledge the kind collaboration of The Texas Company, the Continental Oil Company, the Tide Water Associated Oil Company, the Texas Seaboard Oil Company, and others, through whose courtesy it has been possible to illustrate this paper with examples of actual field work.

comprehensive study of the relation of geological structure in oil-bearing regions and geothermal gradients. C. E. Van Orstrand, of the United States Geological Survey, who was placed in charge of this program, and others, have published during recent years several interesting papers on the subject.

The method most commonly used in these temperature studies has consisted in lowering maximum mercury thermometers into the wells to known depths, allowing them to remain at these depths until they registered the temperature of the surrounding medium, and then pulling the thermometers out for reading. One or more thermometers were placed on the line and readings were made at intervals of 100-500 feet. Temperatures thus obtained when plotted against depth gave a general gradient.

Electrical resistance thermometers were also used by Van Orstrand in some of his early work in eastern oil fields. However, certain difficulties encountered with the measuring circuit led to the temporary abandonment of this method.

In all these measurements, inasmuch as the true rock temperature is desired, the fluid which fills the well must be in thermal equilibrium with the surrounding rock. In some locations, however, this condition is difficult to obtain, especially in rotary wells. Here many interfering conditions may affect the temperature of the rocks to a considerable distance from the well. Obviously the most important interference is the circulating mud.

Experiments made in numerous oil fields show that holes drilled with rotary tools should remain idle for a period of approximately 30 days or more in order to obtain equilibrium after drilling has stopped.

Although the true geothermal gradient and, in particular, its variation with subsurface structure, is unquestionably useful from the geological point of view in the search for new oil fields, it is obvious that the protracted period of idleness required to obtain equilibrium in a well, and the smooth gradient obtained, make such measurements of little practical value to the petroleum engineer.

The development of a successful technique and equipment for making electrical surveys of deep wells made it possible to design electrical temperature-measuring devices capable of being successfully run inside of drill holes. Among them is a resistance thermometer which has been in use for several years, this as a rule being used in conjunction with the electrical survey.

The use of this thermometer in conjunction with a recorder which gives a continuous record of temperature changes as the instrument is lowered into the well, has introduced into the study of subsurface

thermal conditions, methods of study entirely different from the earlier ones, and has provided a new tool of considerable value to the petroleum engineer.

The first measurements with the resistance thermometer were made in wells which had been idle for a sufficient time, about two or three days, to approximate conditions of equilibrium. The gradient obtained, while not the true gradient, was expected to give a good approximation to it and it was believed that, due to differences of thermal conductivity between the various formations, changes in gradient would indicate the locations of these formations in the hole. This technique, however, proved unsatisfactory for the following reasons: (1) it was extremely difficult to find wells in which the condition of approximate equilibrium was obtained; (2) the temperature curves obtained were so smooth, and the changes in slope were so gradual, that they could not be used to locate varying formations encountered in the drill hole. This lack of marked change in the gradient, amongst the interbedded formations in the oil fields, is due to leakage of heat through the mud into the well during the long period of quiescence. This leakage masks all changes of gradient, and, in particular, eliminates entirely the effects due to thin strata. The procedure was not abandoned, however, and all the data accumulated during the application of this method were carefully studied and analyzed. This resulted in the discovery of a new technique which proved to be far superior to the gradient method for the solution of problems interesting to the petroleum engineer.

The new technique takes advantage of the phenomena which gave trouble originally in the determination of geothermal gradients, namely: the lack of thermal equilibrium between the fluid filling the hole and the formations. As its principle has already been described in detail in several previous papers, a brief review only is given here.

In a rotary well the temperature of the circulating fluid is very different from that of the formations; it is lower at the bottom, and higher at the top. Thus, when circulation is stopped, the mud will begin to warm up in the lower part of the hole and to cool at the top. The speed of this exchange of heat, however, will depend on the nature of the rocks traversed by the drill hole. For instance, water sands which have high thermic conductivity and high thermic capacity, will release their heat much faster than shales. Therefore, a temperature curve recorded in the well a short time after the circulation has been stopped will distinguish the several formations by means of their varying thermic reactions.

Of course, the results obtained by the new technique differ in a

very significant manner from those obtained by the earlier methods. In particular, the early methods were mostly concerned with the determination of the established earth gradients for the regions in which the wells were located, but they could not give very reliable stratigraphic data. The new method, on the contrary, is more suitable for distinguishing individual strata in a single well. The data of the new method are therefore of more immediate practical value than those derived from the gradient method.

An important practical advantage of the new technique is its high sensitivity. In fact, the temperature changes recorded in wells which are in an evolutive thermal stage are generally of several degrees for small changes of depth. This permits a high speed of recording (generally about 1,000 feet per hour) without the thermic lag of thermometer appreciably impairing the shape of the curve; also, it provides curves which are easily and safely interpreted.

The main applications of temperature surveys in the solution of production problems in the petroleum industry may be listed as follows.

1. Locating high pressure gas and oil sands
2. Logging certain formations, and thus permitting correlation between wells, either cased or not
3. Locating fluid flows
4. Study of movements of fluid behind casing
5. Locating and study of cemented zones

All of these applications have already been discussed elsewhere more or less in detail, and the present paper will treat only the application of temperature measurements to the following two problems.

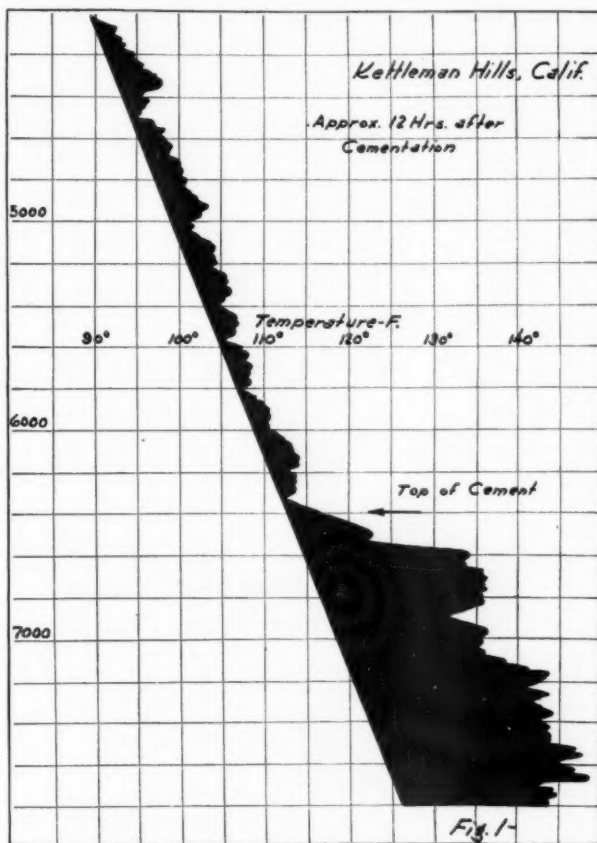
1. Location and study of cemented zones
2. Correlation between wells

LOCATION AND STUDY OF CEMENTED ZONES

Theoretically the quantity of cement necessary for a cement job depends upon several factors which are easy to determine, namely: the size of the casing and of the hole, and the length of the section to be cemented. However, the hole is generally far from regular. Caves or heaving formation may be present, sands may absorb the slurry, and channeling may occur. The actual height of the cement column is generally somewhat below or above the calculated height. It is therefore important to check this level before attempting to produce from the oil or gas encountered in the well.

As the cement generates a considerable quantity of heat while setting, the thermometric method is ideally adapted to the solution of this problem.

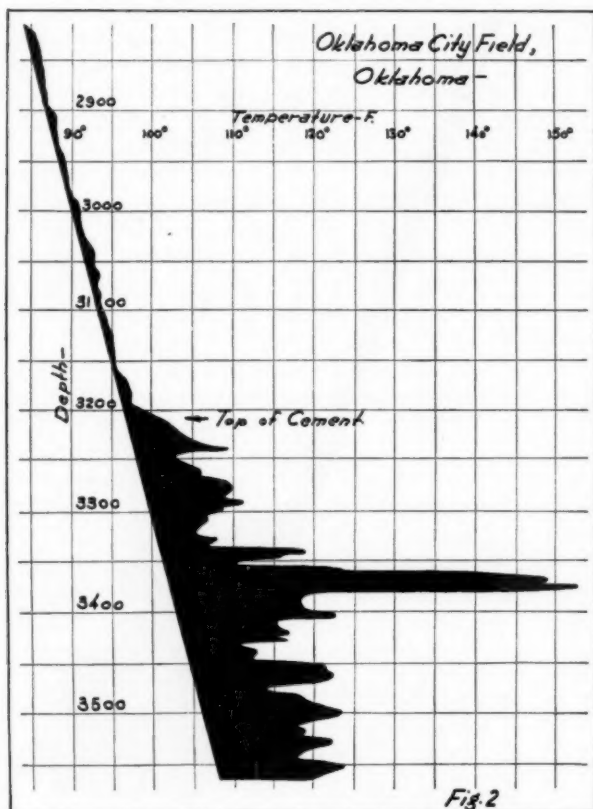
Figure 1 is an actual example of a temperature survey made for the purpose of locating the top of the cement in a well in California. Anomalies of 20°F. are indicated opposite the cemented section. The survey was made approximately 12 hours after the cement job had



been completed, and even after so short a time the top of the cement is clearly and definitely shown at 6,500 feet (where a sharp rise in temperature is indicated).

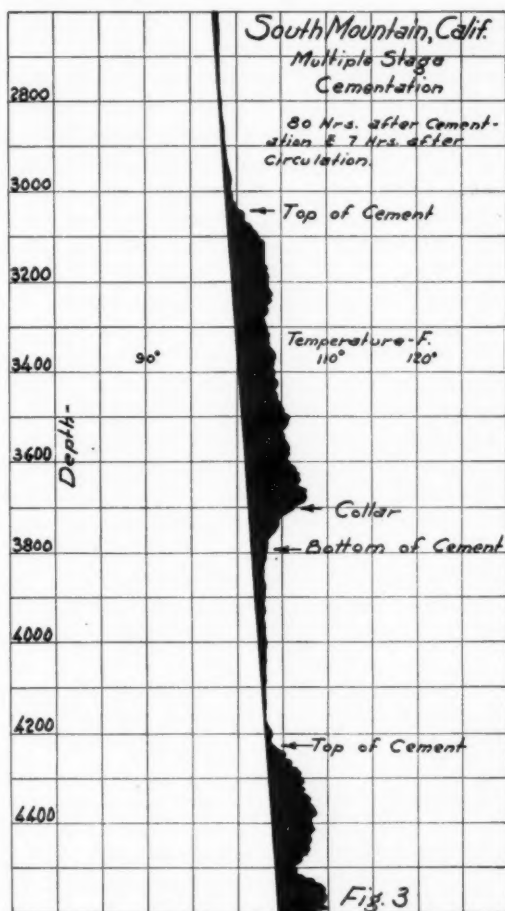
To facilitate the comparison between all the examples of cemented wells referred to in this paper, the temperature scale is the same. The depth scale, however, varies.

When the cement top, as determined by a temperature survey, is found lower than was calculated, it may be concluded that some cave or absorbing layer is present. In either case, the excess of cement in such portions will correspond to increased thermal anomalies on the



log. On the curve, Figure 2, such an anomaly is seen at 3,375 feet. Its magnitude is 40°F. above the rest of the cemented section, the presence of which in turn is indicated by an average increase in temperature of approximately 10°F. above the average gradient line. The cave corresponding to the 3,375-foot anomaly was caused by the hole being sidetracked at this point.

When, on the contrary, the cement top is found to be higher than was calculated, it is probable that channeling exists, and the oil sands which are counted on to produce may not be protected from water infiltration from adjacent water sands.



The exact segregation of the cement behind the casing can not be determined from the temperature curve. As will be shown later, it is not certain that the sections showing the highest thermal anomalies will correspond to those in which the quantity of cement is the largest,

with the exception, of course, of very large anomalies, like that shown on the preceding figure.

In the present state of the art, all that can be expected from a temperature survey is to ascertain whether there is a reasonable quantity of cement in a given section of the casing. This information alone, compared with the calculated quantity of cement, gives sufficient data regarding the safety of the cement job.

Figure 3 is an example of a survey made in a well after multiple-stage cementation. Cement was squeezed from the casing shoe and also from perforations made at 3,700 feet. The temperature curve, taken about 3 days after completion of the job, shows that the entire section between 3,800 and 4,230 feet was not cemented. If there are water and oil sands in this section, it is obvious that production of the oil series in this section will not be possible unless another squeeze job is done.

The rate of exchange of heat between the cement and the surrounding formations depends on several factors, in particular: (1) interval of time between the completion of the cement job and the survey; (2) nature of the formation; (3) temperature of the formation.

To determine exactly the influence of time, it is necessary to make several runs in a specified well during a period of several days. This has not yet been feasible, and thus far the influence of this factor has been determined only from data obtained from different wells.

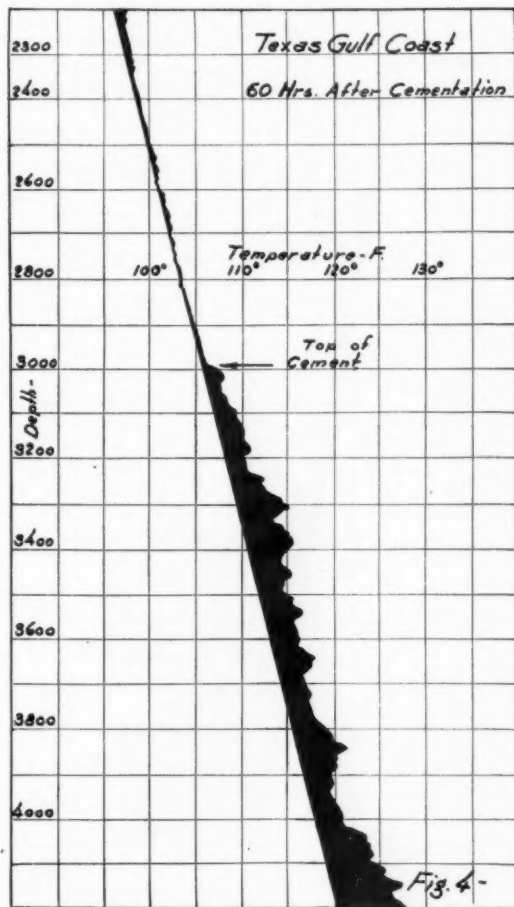
When a quick-setting cement is used, as is the common procedure, the cement reaches its maximum temperature a few hours after completion of the job. From a theoretical standpoint, this time is evidently the most suitable for the survey. This is true also from a practical standpoint, as at that time the well is idle waiting for the cement to set.

After this particular time the heat evolved by the cement is dissipated progressively by the formations more rapidly than it is generated, and the thermic phenomena will gradually disappear.

If the formations surrounding the hole have very large thermal capacity and thermal conductivity, the heat generated by the cement will be dissipated within a much shorter time than it will be if the value of these parameters is small. In the sands and shales generally encountered in oil fields, the heat evolved by a cement job is gradually dissipated until there is only a difference of a few degrees after a period of 4 or 5 days. When a week has elapsed the location of the cement is extremely difficult.

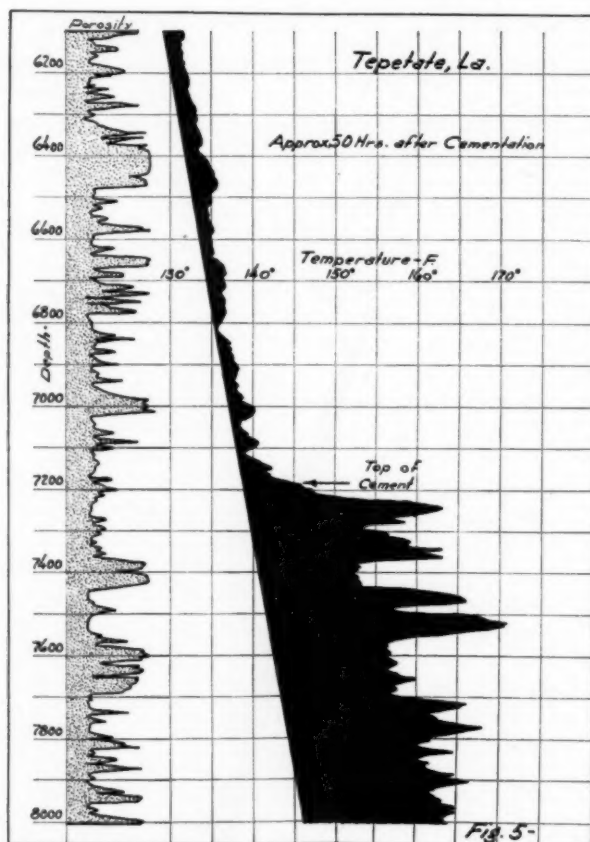
Figure 4 is a temperature curve of a well in the Gulf Coast 60 hours after cementing. The increase of temperature opposite the

cemented section is only about 4° as against more than 10° shown in the previous examples. This difference is mostly due to the length of time involved after cementing.



The second important factor influencing the rate of exchange of heat between the cement and the surrounding formations is that of the thermal properties of the rocks. It may, therefore, be expected that the study of the cooling of the cement will reflect the thermal nature

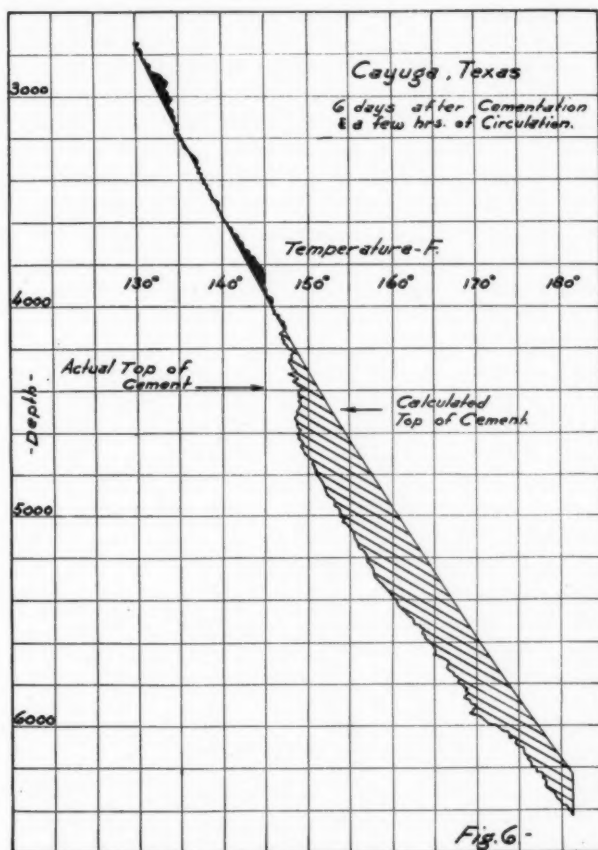
of formations. For instance, water sands which have very high thermal capacity and conductivity will allow the heat generated by the cement to escape much more easily than will the shales. Figure 5 is an example of a temperature curve made about 50 hours after the



cement job was completed. Besides a very clear determination of the top of the cement, as the curve reveals—by comparison with the electrical porosity curve—there is, in the section cemented, an important temperature depression peak opposite each sand.

The temperature of the formation also influences the shape of a

curve recorded in a hole after a cement job. All other factors being equal, the magnitude of the thermal anomaly produced by cementation will vary with the difference between the temperature of the setting cement and that of the adjacent formations. As a consequence,



locating cemented zones is much easier at shallow depths where the formations are cool than at great depths where they are hot. At very great depths, the problem may be impossible to solve by the thermometric method because the temperature of the setting cement may be equal to the temperature of the surrounding formations.

It might even be that in wells drilled to depths of more than 12,000 feet, as the temperature of the cement slurry would be much lower than that of the bottom formations, the cement placed behind the casing would be cooler than those formations, even in the period of setting. Consequently, the cemented zone should be indicated by a negative thermometric effect in such very deep wells.

Thus far, we have no actual example of this condition. However, we do have a temperature curve under conditions that are theoretically similar to those just outlined. The well (Fig. 6) is more than 8,700 feet deep. Casing was set at this depth and cemented from the bottom with 350 sacks of cement. In addition, another 350 sacks were squeezed through perforations at 6,635 feet. Calculations indicate that full cementation should have been obtained from 4,500 feet to bottom. The cement mixture was made by using 10 tons of ice with a final temperature of 40°F.

The temperature curve shows a sharp negative anomaly below 4,400 feet, which, in our opinion, is due to the presence of the cool cement below that level.

Among other factors which play an important part in the problem of locating cemented zones by temperature measurements, there is one which may change entirely the thermal state of the well; this is the circulation of mud or water. It is a fact that if, prior to the temperature survey, a cold fluid is circulated after the cement job is completed, the thermal anomalies opposite the cemented section will tend to disappear. If the circulation lasts for too long a time, the location of the cement will therefore be impossible.

Figure 7 illustrates this influence. Curve 1 was made 3 days after cementing. It shows an increase in temperature of about 7° in the cemented section over that in the non-cemented section. In Curve 2, made after a few hours of circulation, the anomaly is reduced to 2°-3°.

CORRELATION BETWEEN WELLS

To some extent, the logging of geological strata traversed by a drill hole is feasible by means of temperature measurements.

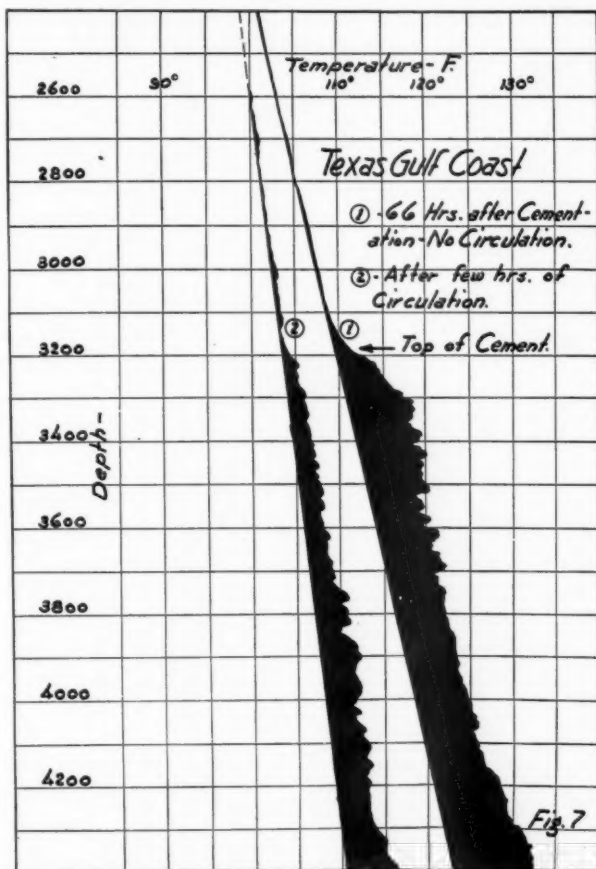
Because of the high thermic conductivity and thermic capacity of the water sands, the rate of exchange of heat between the mud and the formations, after the circulation has been stopped, is much larger opposite these sands than opposite shales.

A temperature curve made a few hours after circulation has ceased should therefore show temperature changes at each geological contact.

TEMPERATURE MEASUREMENTS IN DRILL HOLES 801

Figure 8 is an example in a cased well at Lake Peigneur, Louisiana, 15 hours after circulation was stopped.

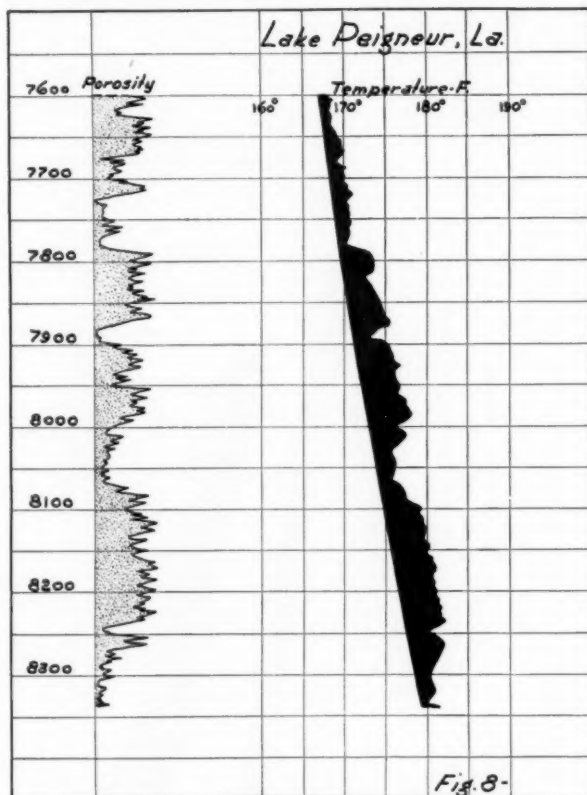
Comparison of the temperature curve with the electrical porosity curve plotted on the left, shows increases of temperature in the sands



of about 3° above those in the shales. The temperature scale is the same as for the examples given in connection with the discussion of cementation.

To derive the best result by this method it is of course necessary

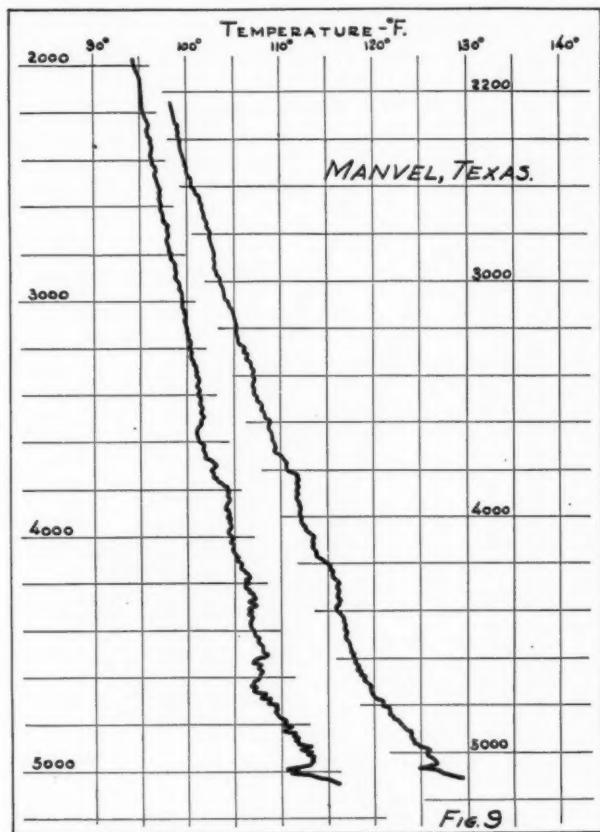
that the measurements be made within a reasonable time after the circulation has been stopped—say 24 hours. After a longer period the curve will gradually flatten, tending toward the true gradient, and of course, under these conditions, no accurate logging is possible.



Although the foregoing example shows strikingly the different formations traversed by the hole, the problem of logging formations by temperature measurement has proved difficult in many cases. In fact, many temperature curves show abnormalities which seem to be without apparent relation to the nature of the formations. On the other hand, many important geological changes, although revealed by the electrical logs, do not appear clearly on the temperature curves.

TEMPERATURE MEASUREMENTS IN DRILL HOLES 803

This condition is probably due to unknown changes in the thermic properties of the geological formation inside of an apparently homogeneous stratum. Also, chemical reactions between the mud and the formations may have an influence, even after the well has been cased.

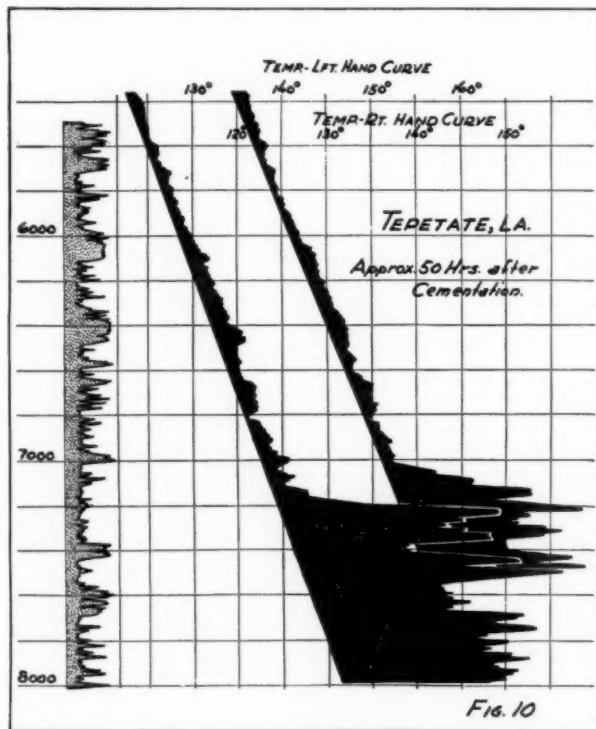


Numerous surveys have shown that a temperature curve made in a well can not be correlated and does not correspond with the geological log or electrical log.

It is probable, however, that when enough data shall have been accumulated, the interpretation of these temperature anomalies can be rationally made.

While this unfortunately is not possible for the time being, it is nevertheless true that the comparison of temperature curves in a certain area shows a striking similarity in shape, thus suggesting the idea of using them for correlation purposes.

Figure 9 is a chart made with this purpose in view. Although far from being perfect, this example shows that temperature curves



which, taken singly, would be valueless, on comparison give interesting information where no other source of information is available.

This possibility is based on the principle that several of the disturbing interferences which alter the shape of the temperature curves are reliable thermic markers which can be correlated throughout wide areas. Some of these markers are not noticeable on the electrical logs.

The curves shown in Figure 9 were run in open holes. However, in cased holes, also, the same possibility exists.

Figure 10 is an attempt at correlation in two cased wells at Tepe-

tate, Louisiana. Besides showing clearly the top of the cement, the curves can be readily correlated. These readings were made in wells recently cemented. It is probable that better results could be obtained in the uncemented sections of the holes, had the measurements been made under more favorable conditions, namely: thermal conditioning of the well a few hours before the survey.

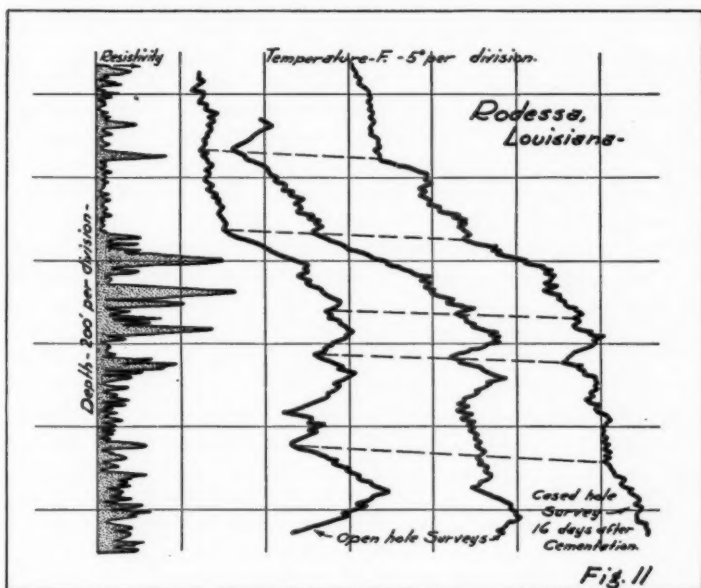


Figure 11 is an example of correlation between three wells at Rodessa, Louisiana. One of them was cased and cemented, and the two others were open when the survey was made. The resistivity log plotted on the left shows that while some of the thermal anomalies correspond, in this particular example, to geological changes of formation, several of them are not shown on the electrical log.

The distance between the most distant wells of this chart is $1\frac{1}{2}$ miles.

Although it is quite evident that temperature measurements in wells are far from being capable of giving the accurate and complete information which the electrical logs now give, the foregoing three examples show that in some cases such measurements can be used to correlate wells already cased, where no other method of investigation is now possible.

GEOLOGICAL NOTES

PRAIRIE BLUFF CHALK AND OWL CREEK FORMATION OF EASTERN GULF REGION¹

New data on the age and stratigraphic relations of several of the later Upper Cretaceous units of the eastern Gulf region have shown the desirability of modifying their generally accepted classification. These changes are indicated in a correlation chart covering the Cretaceous deposits of the Atlantic and Gulf Coastal Plain and trans-Pecos Texas, prepared by L. W. Stephenson and P. B. King, and recently transmitted by the Director of the Geological Survey to C. O. Dunbar, Chairman of the Committee on Stratigraphy of the National Research Council, for publication by that committee.

The Selma chalk, as heretofore defined in west-central Alabama and east-central Mississippi, includes 930 feet of Upper Cretaceous strata (as measured in a well at Livingston, Alabama), lying between the Tombigbee sand member of the Eutaw formation below, and the Midway group (Eocene) above. This section is composed essentially of chalk which, however, differs considerably in purity in its different parts. Traced both eastward in Alabama and northward in Mississippi and Tennessee, the Selma chalk merges laterally at differing distances in its different parts, into non-chalky beds of sand, marl, and clay. The upper 50 feet, more or less, of the chalk, where it is most fully developed, is a hard brittle facies characterized by the presence, in its lower part, of great numbers of phosphatic internal molds of mollusks and other marine organisms and phosphatic nodules. This upper chalk extends eastward from the Mississippi state line in a narrow belt of outcrop through Sumter, Marengo and Wilcox counties, and in the two last-named counties overlies a non-chalky glauconitic sand of Selma age which has been mapped under the name Ripley formation. These relationships are shown on the geological map of the state, which accompanies Special Report No. 14, of the Geological Survey of Alabama, 1926.

At Prairie Bluff on Alabama River in Wilcox County the phosphatic chalk is about 12 feet thick and overlies the sandy beds of the Ripley with an angular unconformity; it is unconformably overlain by sandy beds of the Midway group (Eocene). The base of the chalk is about 50 feet above medium low water. The chalk in this section

¹ Published by permission of the director, United States Geological Survey, Washington, D. C.

was called Prairie Bluff limestone by Winchell in 1857.² Stephenson,³ in 1917, revived Winchell's name and treated the chalk unit as a tongue of the Selma chalk extending eastward from the main body of the Selma in Sumter County.

From Sumter County, Alabama, the upper chalk extends north-westward into Mississippi in a narrow strip through Kemper, Noxubee, Oktibbeha, Clay, Chickasaw, and Pontotoc counties, and into Union County. From Noxubee County northward this chalk overlies the southward extension of the Ripley formation, a sandy, non-chalky unit of upper Selma age. Stephenson, in 1917,⁴ considered the phosphatic chalk, where it overlay the Ripley formation, to be a tongue of the Selma, and he named it the Oktibbeha tongue. Throughout its extent in Mississippi this phosphatic chalk unit is now known to be in unconformable relationship with the beds which underlie it; at one place in Noxubee County it overlaps upon the Selma chalk proper, cutting out a considerable thickness of that unit; its basal beds are everywhere characterized by their phosphate content.

From the foregoing account it appears that the upper phosphatic zone of the Selma chalk of previous papers, and the contemporaneous so-called Prairie Bluff and Oktibbeha tongues of the Selma, constitute a persistent lithologic unit generally 50 feet or less in thickness, extending from Wilcox County, Alabama, to Union County, Mississippi, a distance of more than 200 miles. Throughout the length of this unit an unconformity separates it from the older beds beneath it, and in places, as at Prairie Bluff, the beds below the unconformity are in obvious angular relationship to those above. The unit carries a distinctive fauna, a considerable part of which is preserved as phosphatic internal molds; the phosphatic material is present mainly in the lower part of the unit, though by no means restricted to the lowermost bed. It is now proposed to raise the Prairie Bluff unit, heretofore called a tongue, to formation rank and to extend the application of the name Prairie Bluff to include the upper phosphatic zone in west-central Alabama and east-central Mississippi, previously considered a part of the Selma chalk, and the unit in Mississippi heretofore called the Oktibbeha tongue of the Selma. The name Oktibbeha is abandoned.

The Prairie Bluff chalk as here redefined is unconformably overlain by strata of the Midway group (Eocene) except in Pontotoc County, Mississippi, where sandy, non-chalky strata, having a maxi-

² A. Winchell, *Proc. Amer. Assoc. Adv. Sci.*, 2d ser., Vol. 10 (1857), pp. 84, 90.

³ L. W. Stephenson, *Jour. Wash. Acad. Sci.*, Vol. 7 (1917), No. 9, p. 250.

⁴ *Op. cit.*, p. 249. See also geologic map in *U. S. Geol. Survey Water-Supply Paper* 576 (1928).

imum thickness of about 15 feet, intervene between the Prairie Bluff and the Midway. These sandy beds appear to be conformable with the Prairie Bluff chalk and are unconformably overlain by the Midway.

Some of the fossils which characterize the Prairie Bluff chalk are here listed. The species marked with an asterisk (*) are, so far as known, restricted to that formation. The others have been recorded from lower stratigraphic positions. The variety of *Exogyra costata* Say with narrow costae, though known from lower positions, first becomes abundant in the Prairie Bluff chalk. The more typical shells of *Exogyra costata*, with medium to wide costae, are abundant in beds immediately below the Prairie Bluff chalk, but are not found in this chalk. *Crenella serica* Conrad is found only rarely stratigraphically lower than the Prairie Bluff chalk.

Characteristic fossils of the Prairie Bluff chalk

| | |
|--|---|
| Coelenterata | <i>*Diploschiza melleni</i> Stephenson (abundant locally) |
| <i>Cliona</i> sp. (abundant) | <i>Liopistha prolexta</i> Conrad |
| Echinodermata | <i>Crassatella vadosa</i> Morton |
| <i>*Hemiaster slocumi</i> Lambert | Gastropoda |
| <i>*Linthia variabilis</i> Slocum | <i>Gyrodes petrosus</i> (Morton) (abundant) |
| Pelecypoda | <i>Gyrodes abyssinus</i> (Morton) |
| <i>*Cucullaea capax</i> Conrad | Cephalopoda |
| <i>Exogyra costata</i> Say (var. with narrow costae; abundant) | <i>Eutrophoceras dekayi</i> (Morton) |
| <i>*Gryphaea</i> sp. (a small undescribed species) | <i>Baculites columna</i> Morton |
| <i>Pecten venustus</i> Morton (common) | <i>Scaphites</i> (of the <i>conradi</i> group) |
| <i>Crenella serica</i> Conrad | <i>Sphenodiscus lobatus</i> (Tuomey) |

In Union County, Mississippi, the Prairie Bluff chalk changes its character rather rapidly by mergence northward along the strike into non-chalky, fine, argillaceous, glauconitic sand and sandy clay which make up the upper 50 feet or less of the Ripley formation of previous papers and maps; the unconformity at the base of the Prairie Bluff chalk has been traced northward at the base of these non-chalky equivalents, as far as northern Tippah County. These equivalent beds carry the well preserved marine fauna of the classic Owl Creek section, 3 miles northeast of Ripley in Tippah County, part of which was described by Conrad as early as 1858.⁵ In 1926⁶ Wade named these upper beds the Owl Creek tongue of the Ripley formation. Because of

⁵ T. A. Conrad, "Observations on a Group of Cretaceous Fossil Shells, Found in Tippah County, Mississippi, with Descriptions of Fifty-Six New Species," *Jour. Acad. Nat. Sci. Philadelphia*, 2nd ser., Vol. 3 (1858), pp. 323-36, Plates 34, 35.

⁶ Bruce Wade, "The Fauna of the Ripley Formation on Coon Creek, Tennessee," *U. S. Geol. Survey Prof. Paper* 137 (1926), p. 9.

the unconformity now known to separate the Owl Creek unit from the main body of the Ripley below, it is here proposed to raise the unit to the rank of formation. The line of separation between the Owl Creek formation and its equivalent, the Prairie Bluff chalk, is necessarily an arbitrary one; it is drawn about where chalk ceases to dominate the lithology. The Owl Creek formation extends from Mississippi into Tennessee, where within a few miles to the north it is overlapped and concealed by the transgressing beds of the Midway group (Eocene). The unit does not terminate, however, in Tennessee, for it reappears again at the head of the Mississippi embayment in Crowleys Ridge in southeastern Missouri.⁷

The studies of the senior author have shown a close faunal relationship between the Prairie Bluff chalk and its equivalent, the Owl Creek formation, on the one hand, and the Corsicana marl of Texas⁸ on the other. The Corsicana marl, a formation of the Navarro group, is a chalky marl lithologically similar to the Prairie Bluff chalk, and it carries a similar fauna with a goodly number of identical species; it is phosphatic in its basal portion and rests with transgressing unconformable relations on the Nacatoch sand, Neylandville marl, and Taylor marl. On the evidence afforded by *Foraminifera*, J. A. Cushman⁹ concurs in this correlation. If the correlation here suggested is correct, it appears that the unconformities at the base of the Corsicana marl and the Prairie Bluff chalk are synchronous and mark an episode of emergence and erosion of Gulf-wide extent, followed by submergence in a shallow, clear sea.

The classification of the Navarro group suggested by Stephenson in the reference given above, has been adopted by the U. S. Geological Survey and will appear in the legend of the new coöperative geological map of Texas now in press. The group is there subdivided in ascending order into Neylandville marl, Nacatoch sand, Corsicana marl, and Kemp clay. The previously mentioned sandy beds which intervene between the Prairie Bluff chalk and the Midway group in Pontotoc County, Mississippi, may correspond in age to the lower part of the Kemp clay.

L. W. STEPHENSON

W. H. MONROE

⁷ F. E. Matthes, "Cretaceous Sediments in Crowleys Ridge, Southeastern Missouri," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 17 (1933), No. 8, pp. 1003-09.

Willard Farrar, "Cretaceous and Tertiary Geology of Southeastern Missouri," *58th Biennial Report of the State Geologist for the years 1933 and 1934* (1935), Appendix 1, pp. 1-35.

⁸ L. W. Stephenson (quoted in Adkins), *Geology of Texas*, Vol. 1, *Stratigraphy* (1933), p. 516.

⁹ Letter dated September 17, 1936.

REVIEWS AND NEW PUBLICATIONS

* Subjects indicated by asterisk are in the Association library and available to members and associates.

*"The Van Oil Field, Van Zandt County, Texas." By RALPH ALEXANDER LIDDLE. *Univ. Texas Bull.* 3601 (January 1, 1936). 79 pp., 27 maps and pls. Price, \$1.50.

This publication, which was ready for distribution early this year, is one that the petroleum industry and the petroleum geologist have looked forward to for some time. The text consists of 79 pages and is supported by 27 maps and plates. The petroleum geologist will be greatly interested in the unusual complexity of the Van producing structure. The conclusions drawn as to the period of accumulation and origin of oil, as well as the periodical growth of the Van structure, will furnish him food for thought.

The Van field, with its ultimate half billion barrels of oil production, which has been operated largely as a unit and in the development of which a thorough and systematic collection of geological information has been achieved, is presented by the author in an admirable manner. As the reader investigates the accompanying maps, he will be struck by the magnitude of the material available from which it has been possible to present such a complete report. He will realize, when he looks back over the usual data obtained from competitive development of oil reservoirs, that this is one of the results that the geological profession obtains from unit operations.

The author places before the public the complete history of the field to the end of 1935. He states that Van was discovered by areal surface geology, was further localized by magnetic, torsion balance, and seismographic work. Prior to drilling the first test, the field was further delineated by core drilling. After a large amount of preliminary work, the first well drilled was a commercial producer and its location proved to be in the heart of the producing structure.

The surface geology and subsurface structure, as developed by drilling, are presented by a series of maps that are complete in detail and clearly illustrate the author's statements. The Van field occupies but 1 per cent of the area of uplift of which it is at the apex. The producing area as mapped on the top of the Woodbine formation (the producing sand) is shown to be an extremely complexly faulted dome, somewhat elongated in a northeasterly-southwesterly direction. The major part of the producing structure lies southeast of and on the upthrow side of a major fault, with a displacement of more than 500 feet, which strikes northeast-southwest. Numerous radial faults are present south of the main fault. On the north side of the major fault and parallel to it is a graben, and immediately north of this feature is a horst. Other parallel features on the northwest seem possible from the data presented. A series of maps from the top of the Midway down to the base of the Woodbine is included and it will take much time and study by the student of geology to unravel all the significant movements presented. The author concludes from all the data available to him that this structural feature is caused by salt movements and that under the producing part of the field the

salt lies at least 8,000 or 9,000 feet below the surface. He presents data on the probable age of the salt, and leans to its source as being from strata of Silurian age.

The author concludes that the origin of oil is from Woodbine strata and that accumulation occurred between Austin and Wilcox time. He feels that the original accumulation occurred when the structure had not yet been broken to its present degree, and that the highest part of the earlier structure was north of the main northeast-southwest striking fault. This conclusion was drawn from the fact that gas was originally found in this north area and did not occur in the structurally higher part of the field on the south, as well as from the presence of sands incompletely flushed of their oil.

The conclusion is drawn that all of the so-called fault-line fields in the Woodbine Basin are in reality faulted older folds, and that such fields are underlain by anticlinal folds on beds older than Comanche. The author further postulates that accumulation occurred on these folds prior to the occurrence of the faulting. He concludes that all of the oil found in beds above the Woodbine in the East Texas Woodbine embayment had its origin in beds of Woodbine age and is migratory from this horizon. The reviewer feels that some exceptions will be made to some of the conclusions drawn.

The field's development, its operation, and a résumé of conditions in the reservoir as oil has been withdrawn, are covered. The history of the field's proration and its water disposal problem are discussed. The unitization of the field and the method of revaluation of participants' interests are set forth.

The author is to be congratulated on the excellent presentation of the subject, as likewise are the men who are acknowledged by the author and who have been responsible for the accumulation and study of the material obtained as the field was developed.

F. E. HEATH

DALLAS, TEXAS
April 29, 1937

Petroleum Production. By WILBUR F. CLOUD. University of Oklahoma Press, Norman, Oklahoma (1937). 600 pp., 280 figs. \$5.00.

Throughout the ever-changing panorama presented in the production of oil and gas, various treatises have been written covering the current trends in production and development technique. It is characteristic of the oil and gas industry that the literature of today is more or less obsolete tomorrow, and the author who would keep abreast of his subjects is virtually forced to supply an endless succession of material if he would keep his readers supplied with "up-to-the-minute" information. Many excellent texts have been so developed in the past, but during the past several years there has been a notable dearth of material in book form, occasioned, perhaps, by the lack of time on the part of well known authors of the past, to rewrite the old texts in the light of more modern practices. Hence, a very opportune occasion was presented, which invited the preparation of a new text.

As stated in the preface, Mr. Cloud has attempted to "assemble in one volume the most pertinent data presented through the various publications of the American Institute of Mining and Metallurgical Engineers, the U. S. Bureau of Mines, the American Petroleum Institute, and the various journals

of the petroleum industry." This in itself constitutes a monumental task. To those who have gathered together all the data on one subject only, from the multifarious sources in the literature above cited, the amount of work involved in covering the entire field of petroleum production can be realized more vividly.

The author's table of contents includes: Legal Phases of Petroleum Production, Oil Sands and Production Relations, Oil Field Development, Oil Field Power and Prime Movers, Oil Well Completion, Flowing Oil Wells, Air-Gas Lift Equipment and Methods, Surface Equipment and Methods for Pumping Wells, Underground Pumping Equipment and Pumping Problems, Cleaning and Reconditioning Oil Wells, Repressuring Oil Sands, Gathering, Gauging, and Shipping Crude Oil, Preparing Crude Oil for the Market, Oil Field Water Problems, The Production of Natural Gas, and Storage and Storage Problems.

In covering such a wide range of subjects involving basic principles of most of the fundamental sciences and their application to the industry, it is possible, and even probable, that the author may present subjects open to considerable controversy. For example, it is unfortunate that the subject of spacing has not been developed by petroleum engineers to a workable basis from a study of fundamentals involved. There is some question whether a text should present the various theories of such controversial subjects, or whether a general discussion would not suffice until such a time as fundamentals could be applied with the general approval of those who have made an exhaustive study thereof. There is also the matter of emphasis placed on the various phases of production. Mr. Cloud has apportioned his material very creditably in this respect. A more direct reference to the source material by means of footnotes would undoubtedly be advantageous for those wishing to delve further into the portions digested by the author.

Although a book covering such a range of subjects may be attacked from various angles, depending upon the particular knowledge and viewpoint of the reader, yet the author is to be commended in his general approach and contribution to the current needs of students, petroleum engineers, and operators in the oil- and gas-producing industry.

H. H. POWER

UNIVERSITY OF TEXAS,
AUSTIN, TEXAS
April 24, 1937

"Drilling Mud: Its Manufacture and Testing." By P. EVANS and A. REID. *Trans. Min. Geol. Inst. India*, Vol. 32 (1936). The Institution of Petroleum Technologists, Aldine House, Bedford Street, Strand, London, England, and The Mining and Geological Institute of India, 27, Chowringhee, Calcutta, India. 236 pp., 98 illus., many tables and formulas. 7×10.5 inches. Price, \$5.00 post free to any address.

This treatise is divided into Part One, "The Manufacture of Drilling Mud," and Part Two, "The Testing of Drilling Mud: Physical Properties—Definition, Measurement, and Application." The authors review the existing literature and discuss experimental results obtained in the laboratories of the Burmah Oil Company. The impelling reasons for this academic inquiry into the subject of drilling muds were difficulties of drilling wells to increased

depths, together with the high drilling costs that have resulted from the use of poor drilling mud in some wells. The scope of the report is limited to discussion of physical properties of drilling muds, and does not treat the chemical aspects of the problem.

Manufacturing methods in central plants, which consist of churning and jetting, are discussed at length. It is pointed out, however, that these methods are equally applicable to individual wells. Central manufacturing plants capable of reclaiming used mud by de-sanding, de-gassing, recovering barytes, and reviving are recommended.

The importance of adequate testing as a means of obtaining drilling mud suitable for specific conditions is stressed. A major part of the report is devoted to extensive discussions of the various instruments and the technique employed in determining weight, viscosity, thixotropy, surface tension, water separation, differential settling, salinity, electrical conductivity, acidity or alkalinity, sand content, colloid content, and plastering power.

The meaning of viscosity, perhaps the most important characteristic of drilling muds, is explained graphically and mathematically. Factors (such as agitation, temperature, and pressure) that affect viscosity, the design and use of viscometers, and the application of viscosity measurements are treated in detail.

Physicists, chemists, and mud technologists engaged in laboratory and research work on drilling muds will find this comprehensive report a valuable reference for its complete review of the work done by previous investigators throughout the world and for results of fundamental research done by the authors. American writers on technical subjects would do well to follow the authors' procedure of summarizing each chapter in simple language and of making the subjects and references easily accessible to the reader.

CHARLES B. CARPENTER

DALLAS, TEXAS
April 13, 1937

On the Mechanism of the Geological Undulation Phenomena in General and of Folding in Particular and Their Application to the Problem of the "Roots of Mountains" Theory. By S. W. TROMP. A. W. Sijthoff's Uitgeversmaatschappij N. V. Leiden. 184 pp., 89 figs. Price: fl. 6.90; bound, fl. 8.40.

In the invention of mountain-building theories the geologists of the Netherlands, most of whom gain experience in widely scattered parts of the world, have not been laggards. During recent years two of the theories of this type that have attracted much attention, having been described and discussed by their authors and others in many papers written in several languages, are the "undation" theory of R. W. van Bemmelen and the "buckling" theory of F. A. Vening Meinesz. Dr. Tromp's theory, first published in Dutch in 1933, has not yet become so widely known. In the volume under review, he undertakes to give it an English dress, and to bring it into comparison with the better known theories of his fellow countrymen and others.

In order to furnish a basis for the comparison, he gives first a review of all the geological phenomena that can be grouped together as "undulations." In doing so, he furnishes an interesting discussion, with many illustrations, of many different types of geological folds, their genesis and relations. His

distinction between "bending" and "buckling" is interesting in itself and also for the light it throws on the ideas underlying the Vening Meinesz hypothesis. The discussion is illustrated by photographs of some striking experiments recently made by Kuenen in order to learn how buckling phenomena may be supposed to have affected the crust of the earth. The author continues with discussions of other types of folding, such as Schmidt's "Gleitbretter" mechanism and Helmholtz' "Law of sliding planes." There is also a summary of De Sitter's analysis of similar and parallel folding. In the second half of the chapter devoted to this review of "undulations" the author applies the principles developed in the first half to the explanation of many different kinds of undulations, ranging from ripple marks to Alpine nappes. His summary of the different types of salt structures is likely to be of particular interest to many American geologists.

In Chapter II Dr. Tromp gives critical consideration to the "roots of mountains" theory, which still seems to have about as many friends as foes. Dr. Tromp belongs among the latter. Against it he urges several objections, apparently the most important of which is that in his opinion this theory is inconsistent with the extent to which the "floor" of a geosyncline may rise during orogenesis. His objections are illustrated from conditions in the three mountain regions in which he has had personal experience: the southern Alps, the East Indies, and the Cordillera of North America. From the conditions found in these and other mountainous areas, he holds that mountain-building involves a real oscillation, which takes place in accordance with four "laws of oscillation."

In Chapter III the author considers critically the various classes of theories that may be used to explain gravity anomalies and the genesis of mountain folds. He divides them into two great classes, in the first of which the gravity anomalies are explained by physicochemical decomposition of the sima. The "undation" theory of Van Bemmelen, which is considered as a variant of Haarmann's oscillation theory, is discussed at greatest length, and is concluded to be untenable.

The second class of theories explains the gravity anomalies as due to tangential forces in the earth's crust. One group of theories of this class is based on the assumption that the "specific weight" of the sial crust is constant and its thickness variable. To this group belong the theories of Airy, Vening Meinesz, and Bijlaard, all of which, but particularly the second, are examined at length and rejected. Kuenen's experiments, which duplicated the phenomena assumed by the buckling theory to take place in the earth's crust, are admitted to be brilliant and interesting but are held to be unconvincing.

Turning then to the assumption that "the specific weight of the sial is variable," the author marshals physical data designed to prove that the variability exists, and geological data to prove that upon the fact of its variability may be built a hypothesis that accounts successfully not only for the gravity anomalies of the world but also for the facts of orogenesis. This theory, stated in crude and simple terms that probably do not afford it full justice, is that the sial is capable of sliding upon the sima, because of certain conditions that become operative at times of orogenic activity, and that the movement of sial upon sima is not along a plane but, in accordance with the Helmholtz principle, upon an undulating surface. The downward undulations form the geosynclines, the upward undulations the mountains; and such associated phenomena as vulcanism are merely accompaniments of this funda-

mental process. In attempting to prove that this hypothesis meets all the required tests the author discusses tectonic conditions from many parts of the world, and incidentally reproduces as illustrations the excellent black-and-white tectonic maps of Born's contributions to the *Handbuch der Geophysik*.

At the end of the volume there is an excellent bibliography of tectonic literature consisting of 273 titles.

Although the author did not so intend it, this book is perhaps more interesting for some of the discussions by the way than it is for its central theme. The reviewer, at any rate, can not decide whether or not there is any merit in the attempt to apply the Helmholtz principle of oscillation to tectonic phenomena. The author's conclusions do not seem to follow with absolute certainty from his arguments; and yet, the book is interesting to read, and the geologist is to be envied who can not learn many useful things from reading it. Granting for the sake of argument that Dr. Tromp's theory is no more likely to win its way to universal acceptance than, in his opinion, the Van Bemmelen and Vening Meinesz theories are, the fact remains that here in one book we have an interesting discussion of all three theories, and of many interesting phenomena of structural geology besides.

R. D. REED

LOS ANGELES, CALIFORNIA
May 13, 1937

"Engineering Report on Oklahoma City Oil Field, Oklahoma." By H. B. HILL, E. L. RAWLINS, and C. R. BOPP. *U.S. Bur. Mines Rept. Invest.* 3330 (January, 1937). 240 pp., 69 illus., multigraphed.

This United States Bureau of Mines report is prepared in coöperation with the State of Oklahoma, similar in form and plan to many earlier reports on engineering problems in various other oil fields. However, this volume contains much more material than is usual and is of particular interest because, as is pointed out in the first sentence of the introduction, "Virtually from the date of its discovery in December, 1928, the Oklahoma City oil and gas field, Oklahoma County, Okla., has attracted national and international attention."

The material here assembled is of value to the petroleum engineer as well as the geologist principally for the reason that it constitutes a very extensive and complete record of the facts and figures pertaining to the development of a remarkable oil field which presented many new engineering and political problems resulting from the necessity of producing oil at great depths under the handicap of intense competition due to the presence of many small tracts and under the complex rules of politically enforced proration.

This book contains 240 pages of text and tables, with 69 inserted maps, diagrams, cross sections, *et cetera*. The subject matter is presented under the following major headings.

| | <i>Pages</i> |
|---|--------------|
| Introduction and Acknowledgment (approximately)..... | 2 |
| Geology..... | 3 |
| Production Data by Individual Zones..... | 88 |
| Production Methods and Practices..... | 71 |
| Analysis of Performance Data of Wells..... | 20 |
| Field and Economic Problems and Concluding Statement..... | 49 |

The chapter on geology follows closely the discussion of that subject by McGee and Clawson.¹ This book, however, is of interest primarily to petroleum engineers and, as indicated by the chapter headings here listed, presents a great mass of detailed data, discussions, tables, charts, and figures pertaining to the history and facts relating to production and reserves of oil, gas, water, and the physical behavior, costs, methods, and materials used in the drilling, equipping, and producing of the many wells. Table 71, page 221, presents the following interesting production figures.

| | Barrels |
|--------------------------------|-------------|
| Past Recovery to July 1, 1936: | |
| Arbuckle zone..... | 17,632,255 |
| Lower Simpson zone..... | 85,163,982 |
| "Wilcox" and Fault zones..... | 221,496,575 |
| Cleveland zone..... | 870,592 |
| Total field..... | 325,163,404 |
| Estimated Ultimate Recovery: | |
| Arbuckle zone..... | 18,000,000 |
| Lower Simpson zone..... | 160,000,000 |
| "Wilcox" and Fault zones..... | 450,000,000 |
| Total field..... | 628,000,000 |

Much of the material and discussion of engineering problems appears to be derived from the findings and work of the engineering committee made up of petroleum engineers representing the various operating companies.

As in preceding reports of this series this volume is multigraphed and it is unfortunate that so much valuable material can not be presented in a more pleasing and permanent form.

R. J. RIGGS

TULSA, OKLAHOMA
May 18, 1937

RECENT PUBLICATIONS

AFRICA

*"The Geology of Part of the Upper Luangwa Valley, North-Eastern Rhodesia," by F. Dixey. *Quart. Jour. Geol. Soc. London*, Vol. 93, No. 369 (Part I for 1937), pp. 52-76; 1 fig., 1 pl., 1 correlation table.

*"The Pre-Karoo Landscape of the Lake Nyasa Region, and a Comparison of the Karroo Structural Directions with Those of the Rift Valley," by Frank Dixey. *Ibid.*, pp. 77-93; 1 pl.

*"Fossil Algae from the Kundelungu Series of Northern Rhodesia," by Burton Edward Ashley. *Jour. Geol.* (Chicago), Vol. 45, No. 3 (April-May), pp. 332-35; 1 fig.

ARABIA

*"On the Structure of the Arabian Peninsula," by L. Picard. *Geol. Dept. Hebrew Univ.* (Jerusalem), Ser. 1, Bull. 3 (February, 1937). 12 pp., 1 sketch map, 3 cross sections. In English and in Hebrew.

¹ D. A. McGee and W. W. Clawson, Jr., "Geology and Development of Oklahoma City Field, Oklahoma City, Oklahoma." *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 16, No. 10 (October, 1932), pp. 957-1020.

ASIA

Geologie von Asien (Geology of Asia), Erster Band (1937), by Kurt Leuchs. 553 pp., 214 figs. From the series *Geologie der Erde*, edited by E. Krenkel. Gebrüder Borntraeger, Berlin Price, RM 42.80.

AUSTRIA

*"Neue Beiträge zur Stratigraphie und Faunengeschichte des österreichischen Jungtertiärs" (Recent Contribution to the Stratigraphic and Faunal History of the Austrian Upper Tertiary). Part I, "Das niederösterreichische Mittelmiozän" (The Lower Austrian Middle Miocene), by Rudolf Sieber. *Petrol. Zeit.* (Wien), Vol. 33, No. 13 (April, 1937), pp. 1-8; 5 illus.

CALIFORNIA

*"Kern County's 'Little Signal Hill,' " by Don Hillis. *Petrol. World* (Los Angeles), Vol. 34, No. 4 (April, 1937), pp. 63, 65, 66; 2 figs. Discusses how new production discovered along Spellacy anticline near Taft caused a drilling boom in one of California's oldest oil districts.

*"Folding of the California Coast Range Type Illustrated by a Series of Experiments," by Bruce L. Clark. *Jour. Geol.* (Chicago), Vol. 45, No. 3 (April-May, 1937), pp. 296-319; 16 figs.

CANADA

*"Contributions to the Study of the Ordovician of Ontario and Quebec," by A. E. Wilson, J. F. Caley, J. C. Sproule, and V. J. Okulitch. *Canada Geol. Survey Mem.* 202 (1936). 133 pp., 4 figs., 9 pls. Pt. I, "A Synopsis of the Ordovician of Ontario and Western Quebec and the Related Succession in New York," by Wilson. Pt. II, "The Ordovician of Manitoulin Island, Ontario," by Caley. Pt. III, "A Study of the Cobourg Formation," by Sproule. Pt. IV, "The Black River Group near Montreal," by Okulitch.

ENGLAND

*"The Carboniferous Limestone of the Mitcheldean Area, Gloucestershire," by Thomas Franklin Sibly and Sidney Hugh Reynolds. *Quart. Jour. Geol. Soc. London*, Vol. 93, No. 369 (Part I for 1937), pp. 23-51; 4 figs., 3 pls.

GENERAL

*"Theory of Oil and Gas Accumulation by Retreat and Advance of the Salt-Water Table," by James H. Gardner. *Oil Weekly* (Houston), Vol. 85, No. 5 (April 12, 1937), pp. 18-19. Knowledge that salt water will prevent oil or gas rising to the surface is basis for entirely new theory that their accumulation is the result of the retreat and advance of the salt-water table as orogenic movements of uplift and depression took place, which would create a water drive and push the oil and gas ahead of it into existing structural traps.

*"Magnetic Method of Orienting Cores," by G. L. Kothny. *Petrol. Engineer* (Dallas), Vol. 8, No. 7 (April, 1937), pp. 116, 118; 2 illus. *Petrol. World* (Los Angeles), Vol. 34, No. 4 (April, 1937), p. 83; 2 illus. *California Oil World* (Los Angeles), Vol. 30, No. 8 (April 20, 1937), p. 26; 2 illus.

*"Produccion de Petroleo" (Production of Petroleum). "I. Características físico-mecánicas de un yacimiento petrolífero (Physical-Mechanical Charac-

teristics of an Oil Reservoir), by Enrique P. Canepa. *Boletín de Informaciones Petroleras* (Buenos Aires), Vol. 13, No. 148 (December, 1936), pp. 89-130; 12 figs.

*"Practical Graphical and Approximation Methods for Dip-Shooting Calculations," by Sylvain J. Pirson. *Oil Weekly* (Houston), Vol. 85, No. 7 (April 26, 1937), pp. 22-34; 12 figs.

*"Interrelationship of Geology and Geophysics," by O. L. Brace. *Ibid.*, pp. 35-44.

"Das Ozarkland—ein Bergbaum in den inneren Ebenen Nordamerikas" (The Ozarks—a Mountain Region in the Interior Plain of North America), by Rudolf Schottenloher. Reprint from *Amerikanische Landschaft*. 128 pp., 17 figs. Paper cover. 8.25×10.75 inches. Edited by Erich von Drygalski, Geographical Institute of the University of München. Published by Walter de Gruyter and Company, Berlin and Leipzig (1936).

An Introduction to Historical Geology, with Special Reference to North America, by William J. Miller. 499 pp., 372 figs. 4th edit. (1937). D. Van Nostrand Company, New York. Price, \$3.25.

The Science of Petroleum. A comprehensive treatise of the principles and practice of the production and refining of mineral oil to be published by the Oxford University Press in July, 1937. Editors: A. E. Dunstan, A. W. Nash, B. T. Brooks, H. T. Tizard, assisted by 21 associate editors from various countries. More than 300 authorities contribute about 400 articles. Prospecting, production, refining, transportation. 3 Vols. Quarto. Fully illustrated. Oxford University Press, Amen House, London, E. C.4. Price, 15 guineas net.

"Bausteine zu einem System der Tektogenese" (Building-stones in a System of Tectogenesis), by Franz Ed. Suess. Vol. 13, No. 42 of *Fortschritte der Geologie und Paläontologie*, edited by W. Soergel. 1. Periplutonic and enorogenic regional metamorphism in its tectogenetic significance. 86 pp., 7 figs. Gebrüder Borntraeger, Berlin (1937). Price: single copy, RM 9; in group of 4 related numbers of the *Fortschritte*, RM 7.20. 25 per cent discount outside Germany (except Switzerland and Palestine).

Der Abbau der Gebirge. Vol. 1: Der alpine Bauplan (Denudation of Mountains. Vol. 1: Alpine Structure), by Ernst Kraus. 352 pp., 57 figs., 8 cross sections. Gebrüder Borntraeger, Berlin (1936). Price: RM 30; cloth, RM 32.20. Foreign discount.

Geotektonische Forschungen, edited by H. Stille and Fr. Lotze. No 1: "Zur germanotypen Tektonik I" (Geotectonic Research. No 1: German Type Tectonics I), by H. Stille, Fr. Lotze, E. Lemke, H. J. Martini. 78 figs., 8 pls. Gebrüder Borntraeger (1937). Subscription price: if No. 1 and 3 subsequent numbers are ordered, RM 6.70 each. Foreign discount.

GULF COAST

*"Changing Conception of Structural Features in the Gulf Coast Area," by Robert P. Clark. *Oil and Gas Jour.* (Tulsa), Vol. 35, No. 48 (April 15, 1937), pp. 87, 88; 5 illus.

*"Electrical Coring Practices on the Gulf Coast," by L. W. Storm. *ibid.*, pp. 145-52; 3 figs.

"Some Causes of Blow-Outs During Drilling and Means of Prevention, with Special Reference to the Gulf Coast Region," by Charles B. Carpenter. *United States Bur. Mines* (Washington) *I. C.* 6938 (1937). Information Division, U. S. Bur. Mines, Washington, D. C. Free.

INDIANA

*"Middle Devonian of Southern Indiana," by D. G. Sutton. *Jour. Geol.* (Chicago), Vol. 45, No. 3 (April-May, 1937), pp. 320-31; 1 fig.

KANSAS

"Protection of Fresh-Water Horizons in Oil-Producing Areas, with Special Reference to Kansas," by C. J. Wilhelm. Printed by Kansas State Board of Health (April, 1937). 15 pp., 7 illus. Information Division, U. S. Bur. Mines, Washington, D. C. Free.

**Geologic Map of Kansas* (1937). Prepared by the State Geological Survey of Kansas (Lawrence). Edited by R. C. Moore and K. K. Landes. Shows 92 outcropping geologic units in colors, patterns, and lines. Size, 40×51 inches. Scale, 1:500,000 (approx. 8 miles to the inch). Price: paper, \$1.00; mounted on cloth, \$2.00.

**Oil Weekly* (Houston), *Western Kansas Number* (May 3, 1937). Contains articles by Marvin Lee, Grady Triplett, L. J. Logan, Frank B. Taylor, and George W. Baughman. Insert map of Kansas showing productive geological formation of each oil field.

MICHIGAN

**Michigan Geology. Progress Bibliography. Part I* (March, 1937), by Duncan Stewart, Jr. 23 mimeographed pp. 366 items from *Amer. Jour. Sci.* (1819-1936), *Jour. Geol.* (1893-1936), *Amer. Mineralogist* (1916-1936), *Papers Michigan Acad. Sci., Arts, Letters* (1923-1936). Address: Duncan Stewart, Jr., Michigan State College, East Lansing, Michigan. Price, \$0.25.

Ibid. Part II (in preparation). To include items from *Econ. Geol.*, *Jour. Sed. Petrology*, *Contrib. Univ. Michigan Mus. Paleontology*, *Bull. Geol. Soc. America*, *Bull. Amer. Assoc. Petrol. Geol.*

MONTANA

*"The Structural Geology of the Livingston Peak Area, Montana," by Edward C. H. Lammers. *Jour. Geol.* (Chicago), Vol. 45, No. 3 (April-May, 1937), pp. 268-95; 5 figs.

OKLAHOMA—KANSAS

"Fossil Plants from the Stanley Shale and Jackfork Sandstone in South-eastern Oklahoma and Western Kansas," by David White. *U. S. Geol. Survey Prof. Paper 186-C* (March, 1937), pp. 43-67, pls. 10-14. Price, \$0.10. Supt. Documents, Govt. Printing Office, Washington, D. C.

*"Estimate of Natural-Gas Reserves for the Layton, Oolitic, and Oswego-Prue Horizons in the Oklahoma City Oil Field," by R. E. Heithecker. *U. S. Bur. Mines Rept. Inves.* 3338 (April, 1937). 33 mimeographed pp., 11 figs., 12 tables.

RUSSIA

*"Origin of Pressure in Gas Deposits of Azov Gas-Yielding Region," by A. I. Kosyguin. *Bull. Acad. Sci. U. S. S. R.* (1936); pp. 929-34 with 2 figs., in Russian; pp. 934-36, summary in English.

*"Character of Movements Resulting in Present Relief of Central Asia,"

by G. M. Schoenmann. *Prob. Soviet Geol.* (Moscow), Vol. 7, No. 3 (March, 1937), pp. 226-37. In Russian. Summary in English.

*"Age of Ural Range and Volcanic Cycles of South Ural," by D. G. Ojiganov. *Ibid.*, pp. 238-52. Summary in English.

*"Epeirogenic Movements in Northern Part of Region Adjacent to Caspian Sea and Significance of River-Bed Curve in Their Investigation," by N. I. Nicholaev and B. V. Polyakov. *Ibid.*, pp. 253-65; 5 figs. Summary in English.

*"Lower Cretaceous Beds in Transbaikalia," by B. A. Maximov. *Ibid.*, pp. 266-75; 4 figs. In Russian.

TEXAS

"The Geology of Texas, Vol. III, Upper Paleozoic Ammonites and Fusulinids." *Univ. Texas Bur. Econ. Geol. Bull.* 3701 (in press). Pt. 1, "Upper Paleozoic Ammonites in Texas," by F. B. Plummer and Gayle Scott. Pt. 2, "Permian Fusulinidae of Texas," by Carl O. Dunbar and John W. Skinner. Approx. 600 pp., 97 figs., 81 pls. Austin, Texas. Price, clothbound, \$4.00.

"Stratigraphic Relations of the Austin, Taylor, and Equivalent Formations in Texas," by L. W. Stephenson. *U. S. Geol. Survey* (Washington) *Prof. Paper* 186-G (March, 1937), pp. 133-46, Pl. 44, Fig. 7. Price, \$0.10. Supt. Documents, Govt. Printing Office, Washington, D. C.

VIRGINIA

"Some Organic Constituents of a Recent Sediment from Chincoteague Bay, Virginia," by Roger C. Wells and E. Theodore Erickson. *U. S. Geol. Survey Prof. Paper* 186-D (March, 1937), pp. 69-79, Pl. 15. Price, \$0.10. Supt. Documents, Govt. Printing Office, Washington, D. C.

"Some Deep Wells near the Atlantic Coast in Virginia and the Carolinas," by W. C. Mansfield. *Ibid.* 186-I, pp. 159-61, Fig. 8. Price, \$0.05.

ASSOCIATION DIVISION OF PALEONTOLOGY AND MINERALOGY

**Journal of Sedimentary Petrology* (Fort Worth, Texas), Vol. 7, No. 1 (April, 1937).

"The Sediments of Barataria Bay," by W. C. Krumbein and Esther Aberdeen.

"A Study of the Effects of Wind Transportation on Grains of Several Minerals," by Paul S. Marsland and John G. Woodruff.

"Ventifacts from New Mexico," by C. E. Needham.

"Inexpensive Equipment for Reclaiming Heavy Liquids," by George V. Cohee.

**Journal of Paleontology* (Fort Worth, Texas), Vol. 11, No. 3 (April, 1937).

"Cretaceous and Tertiary Pelecypods of the Pacific Slope Incorrectly Assigned to the Family Arcidae," by Philip W. Reinhart.

"Three New Species of the Pelecypod Family Arcidae from the Pliocene of California," by Philip W. Reinhart.

"*Conchopeltis* Walcott, an Ordovician Genus of the Conulariida," by J. Brookes Knight.

"The Paleozoic Rugose Coral Family Paleocyclidae," by R. S. Bassler.

"Three Upper Carboniferous Gastropods from New Mexico and Texas," by George H. Girty.

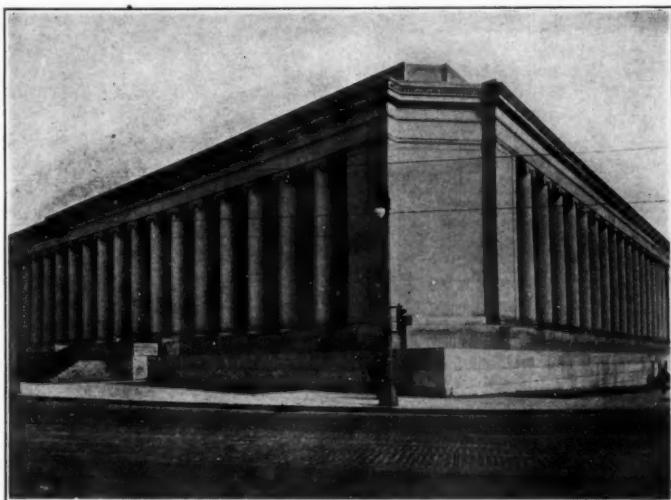
"Keriothecal Wall-Structure in *Fusulina* and Its Influence on Fusuline Classification," by Lloyd G. Henbest.

"*Multisolenia*, A New Genus of Paleozoic Corals," by Madeline A. Fritz.

"An Ophiuran from the Byram Marl (Oligocene) of Mississippi," by Charles T. Berry.

"A Preliminary Review of Certain Families of Diptera from the Florissant Miocene Beds," by Maurice T. James.

"A New Eocene Sea-Urchin from Alabama," by Hubert Lyman Clark.



Mellon Institute, Pittsburgh, Pennsylvania

The mid-year meeting of the Association will be held in Pittsburgh, October 14-16, 1937 (see pages 822-23).

THE ASSOCIATION ROUND TABLE

MEMBERSHIP APPLICATIONS APPROVED FOR PUBLICATION

The executive committee has approved for publication the names of the following candidates for membership in the Association. This does not constitute an election, but places the names before the membership at large. If any member has information bearing on the qualifications of these nominees, he should send it promptly to the Executive Committee, Box 1852, Tulsa, Oklahoma. (Names of sponsors are placed beneath the name of each nominee.)

FOR ACTIVE MEMBERSHIP

Johnson Bennett, Newark, Ohio
A. O. Fischer, Robert C. Lafferty, J. E. Billingsley
Charles Theodore Casebeer, Oklahoma City, Okla.
E. A. Paschal, E. F. Schramm, Frank Gouin
Charles Koogle Clark, Saginaw, Mich.
B. F. Hake, K. H. Schilling, Lynn K. Lee
Jean LaCoste, Rabat, Morocco
J. Harlan Johnson, H. de Cizancourt, Norval E. Baker

FOR ASSOCIATE MEMBERSHIP

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Hyman Corman, San Antonio, Tex.
Julius W. Schmotzer, Worth W. McDonald, Ira A. Brinkerhoff
Lamere John Dworak, Centralia, Ill.
E. F. Schramm, W. G. Green, G. W. Westby
David H. Graham, Los Angeles, Calif.
Harold W. Hoots, Louis N. Waterfall, U. S. Grant
Harold D. Jenkins, Norman, Okla.
Charles E. Decker, Chester F. Barnes, N. W. Bass
Lester Hayden Johnson, Denver, Colo.
F. M. Van Tuyl, W. A. Waldschmidt, J. Harlan Johnson
Robert Arnold Sheldon, San Antonio, Tex.
Hal P. Bybee, Fred M. Bullard, I. R. Sheldon

FOR TRANSFER TO ACTIVE MEMBERSHIP

Charles B. Carpenter, Dallas, Tex.
F. H. Lahee, Francis E. Heath, Harry B. Hill
Charles Rupert Church, Jr., Titusville, Pa.
Glen E. Bader, Dave P. Carlton, J. E. LaRue
William Winchester Valentine, Los Angeles, Calif.
Lawrence Vander Leck, Roy M. Barnes, Earl B. Noble

MID-YEAR MEETING, PITTSBURGH, OCTOBER 14-16, 1937

The mid-year meeting of the Association will be held in Pittsburgh, Pennsylvania, on October 14, 15, and 16, 1937. The Association's Appalachian district representative, R. W. Clark, of the Gulf Oil Corporation at Pitts-

burgh, chairman of the general committee on arrangements, has the cordial support of Pittsburgh educational, scientific, and industrial institutions. This will be the first meeting of the Association east of the Mississippi River since the New York meeting in November, 1926. Though planned particularly for the benefit of members and friends in the eastern districts, this meeting will afford an excellent opportunity for geologists west of the Mississippi to become familiar with recent activities extending from Illinois to New York and West Virginia. The William Penn Hotel is to be convention headquarters.

A tentative outline of the program follows.

October 14, Thursday forenoon. Local trips near Pittsburgh to see old river meanders, intraformational distortion of beds, Mellon Institute, Carnegie Museum, Cathedral of Learning, mechanized coal mine, and other interesting places.

Thursday afternoon. Technical session

Thursday evening. Dinner

October 15, Friday forenoon. Technical session

Friday afternoon. Trip to a steel mill

Friday evening. Smoker

October 16, Saturday forenoon. Technical session

Saturday afternoon. Carnegie Tech.-Notre Dame football game.

Field trips.—A pre-convention trip is planned to leave Pittsburgh early Monday morning, October 11, stopping to look at the peneplains of western Pennsylvania, the mountain front, and the folded Appalachian Mountains of Maryland, Virginia, and West Virginia. It is hoped to spend the first night near New Market, Virginia, and to have an evening trip through one of the beautiful caverns in this vicinity. On the second day the trip will go up the Shenandoah Valley to Lexington, thence across the mountains again to Charleston, West Virginia. In the evening there will be a banquet and a symposium on the oil and gas fields of West Virginia prepared by the Appalachian Geological Society. On the third day, Wednesday, the 13th, the trip continues through the old historic fields in West Virginia, and ends in Pittsburgh.

A post-convention trip, following the football game on Saturday, October 16, is planned to the oil fields in northwestern Pennsylvania, visiting the Drake well on the way, and including the flooding operations at Bradford. This trip will continue all day Sunday, the 17th, but arrangements for departing for home will be made as the participants desire.

General committee.—R. W. Clark, Gulf Oil Corporation, Pittsburgh, chairman; J. G. Montgomery, Jr., Oil City, Pennsylvania; John L. Rich, Cincinnati, Ohio; DeWitt T. Ring, Columbus, Ohio; Daniel J. Jones, Lexington, Kentucky; J. French Robinson, Pittsburgh, K. C. Heald, Pittsburgh, J. E. Billingsley, Charleston, West Virginia; Jack Gaddess, Port Allegany, Pennsylvania.

Arrangements committee.—J. French Robinson, 545 William Penn Way, Pittsburgh, chairman; K. C. Heald, and L. G. Huntley, Pittsburgh. This committee has had set aside, for A.A.P.G. use, a block of 50 seats for the Notre Dame-Carnegie Tech. football game.

Technical program committee.—Thurman H. Myers, Pittsburgh, chairman.

Trip committee.—M. G. Gulley, Box 1166, Pittsburgh, chairman; R. E. Sherrill, Pittsburgh; and Paul H. Price, Morgantown, West Virginia.

ASSOCIATION COMMITTEES

EXECUTIVE COMMITTEE

H. B. FUQUA, *chairman*, Fort Worth, Texas RALPH D. REED, Los Angeles, California
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AT HOME AND ABROAD

CURRENT NEWS AND PERSONAL ITEMS OF THE PROFESSION

W. K. LINK, of the Carter Oil Company, Tulsa, Oklahoma, has been transferred to the Standard Oil Company of Louisiana, Shreveport, succeeding E. V. WHITWELL as head of the geophysical exploration department. Whitwell was recently transferred back to the Carter Oil Company, Tulsa.

The Panhandle Geological Society, Amarillo, Texas, has elected the following officers for this year: president, JERRY KNIGHT; vice-president, C. C. HEMSELL, Columbian Fuel Corporation; secretary-treasurer, B. L. PILCHER, The Texas Company.

WILLIAM BOWIE, former chief of the division of geodesy of the United States Geologic and Geodetic Survey, addressed the Fort Worth Geological Society, April 16, on "Isostasy."

RICHARD W. SHERMAN, formerly chief geologist for the Barnsdall Oil Company, Los Angeles, is establishing consulting geological offices at 1146 Subway Terminal Building. He will be affiliated with the Rieber Laboratories as general representative for California and as consultant in the interpretation of Rieber sonograph records.

H. F. DAVIES has changed his address from Saudi, Arabia, to the California-Texas Oil Company, Ltd., 130 East 43d Street, New York City.

W. M. ANGLE has resigned from the Amerada Petroleum Corporation and accepted a position with the Standard Oil Company of Kansas, 600 Esperson Building, Houston, Texas.

LINN M. FARISH, formerly district geologist for the Sinclair Prairie Oil Company, Ardmore, Oklahoma, is now connected with the exploration program of the Seaboard Oil Company in Persia and Afghanistan.

R. E. COLLOM, vice-president in charge of California operations of the Continental Oil Company, has been elected president of the Kettleman North Dome Association, succeeding WILLIAM REINHARDT.

C. E. EDGERTON, formerly geologist with the Wilcox Oil and Gas Company, has joined the Republic Production Company with offices in the Alamo National Building, San Antonio, Texas.

BURR MCWHIRT has resigned his position as valuation engineer with the Shell Petroleum Corporation, Houston, Texas, and joined the Bureau of Internal Revenue, 1714 Lanie Place, Washington, D. C., as engineer in the oil and gas section of the income tax unit.

BEN R. MILLS, geologist of the Mid-Continent Petroleum Corporation at Tulsa, died April 23, aged 53 years.

R. W. MOSSMAN is employed by the Geophysical Research Corporation with headquarters at Tulsa.

C. N. GOULD, of the National Park Service, gave an illustrated lecture on "The Big Bend International Park of Texas and Mexico" before the North Texas Geological Society, April 30, at Wichita Falls, Texas.

KENNETH L. GOW, formerly district geologist for The Superior Oil Company of California, Shreveport, Louisiana, has been transferred to Mattoon, Illinois. His address is 300 South 17th Street.

HAROLD W. HOOTS, with the Union Oil Company, has been appointed chief geologist for the reorganized Richfield Oil Corporation.

ARTHUR J. TIEJE, professor of geology at the University of Southern California, Los Angeles, will sail for Australia on the *Mariposa* on June 23. He hopes to secure eastern Pacific fossils, especially foraminifera.

The firm of Alexander Anderson, Inc., oil-well surveyors since 1924, has been purchased outright by the Lane-Wells Company (complete oil-well survey and perforating service), Los Angeles, California. BRUCE BARKIS is manager of field operations for Lane-Wells. NORMAN L. DORN is general manager of the Alexander Anderson, Inc., division of Lane-Wells.

REGINALD A. DALY of Harvard University gave six Harris Foundation lectures, April 28-30 and May 3-5, at Northwestern University. The lectures are a series entitled "The Crust of the Earth."

JOHN T. STARK has been appointed chairman of the department of geology and geography at Northwestern University in place of CHARLES H. BEHRE who has asked to be relieved of the chairmanship to devote more time to research. Professor Stark is spending a year in field study of the geology of the Southern Pacific realm and in attendance at the International Geological Congress in Moscow. Professor Behre has been granted a year's leave to attend the Congress and to study European zinc deposits.

VIRGIL R. D. KIRKHAM, consulting geologist of Saginaw, Michigan, discussed the future possibilities of oil and gas production in Michigan at the annual meeting of the eastern district of the American Petroleum Institute in Columbus, Ohio, May 6 and 7.

CARROLL V. SIDWELL, chief engineer of the British American Oil Producing Company, Tulsa, has resigned to become associated with JOHN LEAVELL, independent operator in Tulsa.

FRANK T. CLARK, district geologist; GORDON HEID, his assistant; JOHN S. HEROLD, geological scout; and JOHN S. MADDOX, land man, have moved from San Angelo to Odessa, Texas, where the Empire Oil and Refining Company has its land and geological offices for that district.

On May 2, the Kansas Geological Society took its second field trip of the year. Approximately 35 members went eastward from Wichita to the Flint Hills, and examined the stratigraphy of the lower part of the Big Blue division of the Permian system. JERRY UPP, geologist for the Amerada Petroleum

Corporation, explained the geologic section, assisted by W. A. VER WIEBE, professor of geology at the University of Wichita.

The Geological Society of Washington, D. C., presented the following program on April 28: "Origin of the Oil-Bearing Sands of Northeastern Oklahoma and Southeastern Kansas," by N. W. BASS; "Petroleum Geophysics," by D. C. BARTON.

VINCENT EVANS is working for the Carter Oil Company, Tulsa.

G. E. TASH, recently with the Caribbean Petroleum Company in Maracaibo, Venezuela, has been transferred to the Shell Oil Company at Houston, Texas.

LOUIS C. SASS has been transferred from the Venezuela Gulf Oil Company in Maracaibo to the Mene Grande Oil Company, Apartado 35, Ciudad Bolivar, Venezuela.

ED. BLOESCH, consulting geologist, Tulsa, has an article, "Important Exploratory Well Is Started Near Syracuse, Kansas," in the *Oil and Gas Journal* of May 6.

M. T. HALBOUTY, chief geologist, and ALEX R. DEARBORN, JR., land man, both recently with Glenn H. McCarthy, Inc., have organized the Merit Oil Company at Houston.

GERALD C. MADDOX, geologist with the Carter Oil Company, has been transferred from Oklahoma City to Ponca City, Oklahoma.

SAM W. WELLS, formerly of Okmulgee, is now with the Gilmort Oil Company, 924 Kennedy Building, Tulsa.

U. R. LAVES has accepted a position as geologist with W. A. Delaney, Jr., at Ada, Oklahoma.

W. A. TARR, of the geological department of the University of Missouri, at Columbia, spoke before the Tulsa Geological Society, May 8, on "Occurrence and Origin of Chert."

The Mid-Continent Section of the American Institute of Mining and Metallurgical Engineers held its annual dinner meeting in Tulsa, May 3. DON R. KNOWLTON, general production superintendent of the Phillips Petroleum Company, Bartlesville, spoke on "Future of Well Spacing." R. C. ALLEN, president, and A. B. PARSONS, secretary of the A.I.M.E., spoke on Institute affairs.

The Big Horn Basin-Yellowstone Valley Tectonics field conference is announced for August 3-5, sponsored by the Rocky Mountain Association of Petroleum Geologists and the Yellowstone-Big Horn Research Association, Inc., in cooperation with the Montana Bureau of Mines and Geology, and the Wyoming Geological Survey. The officers of the Rocky Mountain Association of Petroleum Geologists are: H. W. OBORNE, president; E. H. HUNT, first vice-president; W. O. THOMPSON, second vice-president; J. HARLAN JOHNSON, secretary-treasurer. The officers of the Yellowstone-Big Horn Research Association are: NEVIN M. FENNEMAN, president; ROLLIN T. CHAMBER-

LIN, vice-president; W. T. THOM, Jr., secretary; JOHN T. ROUSE, treasurer. The director of the Montana Bureau of Mines is FRANCIS A. THOMSON. The State Geologist of Wyoming is S. H. KNIGHT.

Charles H. SMYTH, Jr., emeritus professor of geology at Princeton University, died on April 4, aged 71 years.

WALTER H. BUCHER, professor of historical geology at the University of Cincinnati, has been appointed chairman of the department of geology and geography.

The seventh annual Field Conference of Pennsylvania Geologists was held in Bradford, Pennsylvania, May 28, 29, and 30. The field trips embraced a study of stratigraphy, structure, and paleontology in the Upper Devonian, Mississippian, and Lower Pennsylvanian in the Bradford Quadrangle and in the Venango oil fields country.

The seventh Pennsylvania Mineral Industries Conference was held at State College, April 30 and May 1. The Petroleum and Natural Gas Section of The Pennsylvania Natural Gas Men's Association held a special symposium.

W. A. MALEY is division geologist for the Humble Oil and Refining Company at Corpus Christi, Texas, succeeding W. K. ESGEN, resigned.

F. C. OWENS has resigned his position as geologist with the Humble Oil and Refining Company to become geologist for the Heep Oil Corporation and the Conroe Drilling Corporation in Corpus Christi.

W. K. ESGEN, formerly with the Humble Oil and Refining Company as division geologist at Corpus Christi, and L. V. MANDRY, formerly land man with that company, are now associated in a partnership at Corpus Christi.

WALTER B. LANG, of the United States Geological Survey, is author of "Sun Symbol Markings" in the *Journal* of the Washington Academy of Sciences, April 15, 1937.

The fifth annual Petroleum Conference of Illinois-Indiana was held, May 29, at Robinson, Illinois. The following papers were presented: "The Nature of Favorable Oil-Bearing Structures in Pennsylvania Formations in Southwestern Indiana," by C. A. MALOTT; "The Seismograph and Its Application to the Illinois Basin," by C. M. BOOS; "The Use of the New Type Gravitometer in Detecting Structures Favorable for Oil," by A. B. BRYAN; "Recent Developments in the Illinois Basin and Their Significance," by A. H. BELL; "Rotary Drilling in Illinois," by W. B. WHITE and F. W. FREEBORN, JR.; "Drilling Problems in the Illinois Basin," by R. W. McILVAIN, JR.; "Oil-Well Cementing Practices," by C. P. PARSONS; "New Methods of Oil-Well Shooting," by PAUL F. LEWIS; "Repressuring Practices," by C. C. HOGG; "Some Thoughts on the Economics of the Oil Industry," by PAUL BLAZER.

ROBERT W. ELLIS, formerly professor of geology at the University of New Mexico and State geologist of New Mexico, died on March 10, aged 68.

FRANK E. ECKERT, manager of Hanley and Bird, Bradford, Pennsylvania, is chairman of the eastern district of the American Petroleum Institute.

L. F. MCCOLLUM, head of the exploration and development department, and F. W. FLOYD, in charge of the production department of the Carter Oil Company, Tulsa, have been elected directors of the company.

HERBERT G. OFFICER, in charge of the land department of the Amerada Petroleum Corporation, Tulsa, Oklahoma, died at Monterey, California, May 18, 1937.

S. ZIMMERMAN has been transferred from the position of computer with the Carter Oil Company to that of seismograph party chief for the Standard Oil Company of Louisiana. His address is Box 486, El Dorado, Arkansas.

GEORGE S. HUME, of the Geological Survey of Canada, in a recent talk before the Canadian Club at Toronto, estimated a potential capacity of 250 million barrels of crude oil on the west flank of the Turner Valley field.

The Carolina Geological Society has been organized with the following officers: president, W. C. HOLLAND, Furman University, Greenville, South Carolina; vice-president, BERLIN C. MONEYSMAKER, Tennessee Valley Authority, Murphy, North Carolina; secretary-treasurer, WILLARD BERRY, Duke University, Durham, North Carolina.

RICHARD G. REESE is geologist for the Standard Oil Company of California. He resides at San Marino.

F. K. G. MÜLLERRIED, of Mexico, D.F., has gone to Australia.

CARL H. BEAL has been appointed a director of the Tide Water Associated at Los Angeles.

BRUCE H. HARTON, of the Amerada Petroleum Corporation, spoke before the Tulsa Geological Society, May 17, on "The Stratigraphy of the Bendian of the Ouachita Mountains, Oklahoma."

LINN M. FARISH, of the Amiranian Oil Company, 39 Broadway, New York City, reports that the following geologists have been sent to Persia: FRANK REEVES, formerly of the United States Geological Survey, LESTER S. THOMPSON, HENRY HOTCHKISS, and BENNETT FRANK BUIE.

AUGUST F. BECK has resigned from the Carter Oil Company to take charge of the geophysical department of the Indian Territory Illuminating Oil Company, Bartlesville, Oklahoma.

The 100th meeting of the American Association for the Advancement of Science will be held at Denver, Colorado, June 21-26. The Cosmopolitan Hotel is headquarters. Section E (Geology and Geography) opens its program on Tuesday, June 22, meeting with the Society for Research on Meteorites. The remainder of the week will be devoted to papers and field trips, in all of which Rocky Mountain geology will be featured.

CHARLES E. YAGER, chief geologist for the Texas Pacific Coal and Oil Company, at Forth Worth, has been appointed to the directorate of the company.

WALTER S. OLSON has been transferred from the Colombian Petroleum Company to the Los Angeles office of The Texas Company.

W. LLOYD HASELTINE, geologist, is employed by the Magnolia Petroleum Company at Midland, Texas.

ROBERT H. WOOD, of Wood Brothers, Beacon Life Building, Tulsa, has been elected president of the Mid-Continent Royalty Owners Association.

LEON J. PEPPERBERG, consulting geologist and engineer, aged 54 years, was killed in an automobile accident, while on his way home at Dallas, Texas, May 12.

The British Association for the Advancement of Science will hold its annual meeting at Nottingham, September 1-8. L. J. WILLS, president of the geology section, will present an address on the Pleistocene history of the West Midlands.

E. W. KRAMPERT, district geologist for the Superior Oil Company of California in the Rocky Mountain district, has resigned from the company. He is temporarily returning to consulting work with offices in Casper, Wyoming.

HAL P. BYBEE, of the faculty of geology at the University of Texas, Austin, has returned to summer work for University Lands. His address is Box 1663, Midland, Texas.

ROLLIN ECKIS has resigned from the geological staff of The Texas Company to become district geologist for the Richfield Oil Corporation in the San Joaquin Valley, California.

H. A. KELLY, formerly with the Bankline Oil Company, and DONALD C. BIRCH, formerly with the Shell Oil Company, have been added to the geological staff of the Richfield Oil Corporation, Los Angeles.

HILLARD W. CAREY has been transferred from Halliburton Oil Producing Company at Houston, Texas, to Erle P. Halliburton, Inc., Antlers, Oklahoma, to watch the 6,000-foot test of that company in Pushmataha County.

STUART SHERAR, W. K. ESGEN, and L. V. MANRY, recently with the Carter Oil Company, Tulsa, and the Humble Oil and Refining Company, Houston, have organized the Trinity Petroleum Company for work in the Gulf Coast region.

C. C. ANDERSON, engineer in charge of the United States Bureau of Mines helium plant at Amarillo, Texas, discussed "Helium and the Problem of Geologic Time," before the West Texas Geological Society at Midland, May 26.

LYNDON L. FOLEY, consulting petroleum engineer, Tulsa, Oklahoma, read a paper on "Proration of Allowable Oil Production" at the meeting of the

American Petroleum Institute at Colorado Springs, June 1-3. The paper is in the *Oil and Gas Journal* of June 3.

The annual field trip of the Appalachian Geological Society, of Charleston, West Virginia, was held May 21-23, 1937, through Highland and Adams counties, Ohio. The party was conducted over the outcrop of the Ohio "Big lime" by WALTER BUCHER of the University of Cincinnati and J. ERNEST CARMEN of Ohio State University. The Ohio Academy of Science participated in the trip. Forty-two members and visitors made up the party.

DEAN MCGEE, formerly chief geologist of the Phillips Petroleum Corporation, is vice-president of the Kerlyn Oil Company in charge of production, land, and geological departments.

H. D. HEDBERG, of the Venezuela Gulf Oil Company, has moved from Maracaibo to Ciudad Bolivar, Venezuela. His new mailing address is Apartado 35.

The Rocky Mountain Association of Petroleum Geologists, Denver, held its annual picnic on June 12. H. W. OBORNE, Colorado Springs, is president, and J. HARLAN JOHNSON, Golden, is secretary-treasurer.

J. H. REGAN has changed his address from Midland, Texas, to Quirequire Camp, Caripito, Venezuela.

GORDON W. HELD, Empire Oil Company, formerly at San Angelo, may now be addressed at Box 926, Odessa, Texas.

L. K. MOWER, who has been employed by the Caribbean Petroleum Company, Caracas, Venezuela, may be addressed at 5128 Reiger Avenue, Dallas, Texas, until July 1. After that date his address will be Bataafsche Petroleum Mij., Carel van Bylandtlaan 30, The Hague, Holland.

JAMES, R. DAY, geologist for the Amerada Petroleum Corporation, has returned to Midland, Texas, after a year and a half's work as field geologist in the Monument field, Lea County, New Mexico.

A. E. MCKAY, formerly with the Indian Territory Illuminating Oil Company, Bartlesville, is now with the Atlantic Refining Company, 716 Giddens-Lane Building, Shreveport, Louisiana.

RAYMOND M. LARSEN has changed his address from Casper, Wyoming, to Oil and Gas Leasing Division, U. S. Geological Survey, Washington, D. C.

V. C. SCOTT, geologist with The Texas Company, has been transferred from the Tulsa office to Oklahoma City, Oklahoma.

GLENN D. ROBERTSON, geologist with the Shell Petroleum Corporation, has returned to Houston, Texas, after spending ten months in The Hague, and seven months in the St. Louis office.

JOHN JANOVY, formerly with the Skelly Oil Company, Pampa, Texas, is now with the Louisiana Land and Exploration Company, Houma, Louisiana.

Mr. and Mrs. CHESTER D. WHORTON announce the arrival of Mary Louise on April 28 at Olean, New York.

J. M. KIRBY may now be addressed in care of The California Company, 330 Continental Building, Denver, Colorado. His old address was the Standard Oil Company of California, San Francisco, California.

EARL S. NEAL, whose address has been the Lago Petroleum Corporation, Maracaibo, Venezuela, is now at 92 San Mateo Road, Berkeley, California.

C. L. MORGAN has changed his address from Atlanta, Texas, to Lion Oil Refining Company, Exchange Building, El Dorado, Arkansas.

CHARLES T. JONES, geologist with the Stanolind Oil and Gas Company, is now located at Casper, Wyoming. His former address was Tucumcari, New Mexico.

EDWARD A. MAYER, employed by the Shell Petroleum Corporation at Vandalia, Illinois, is now in the geophysical division of the same company at Houston, Texas.


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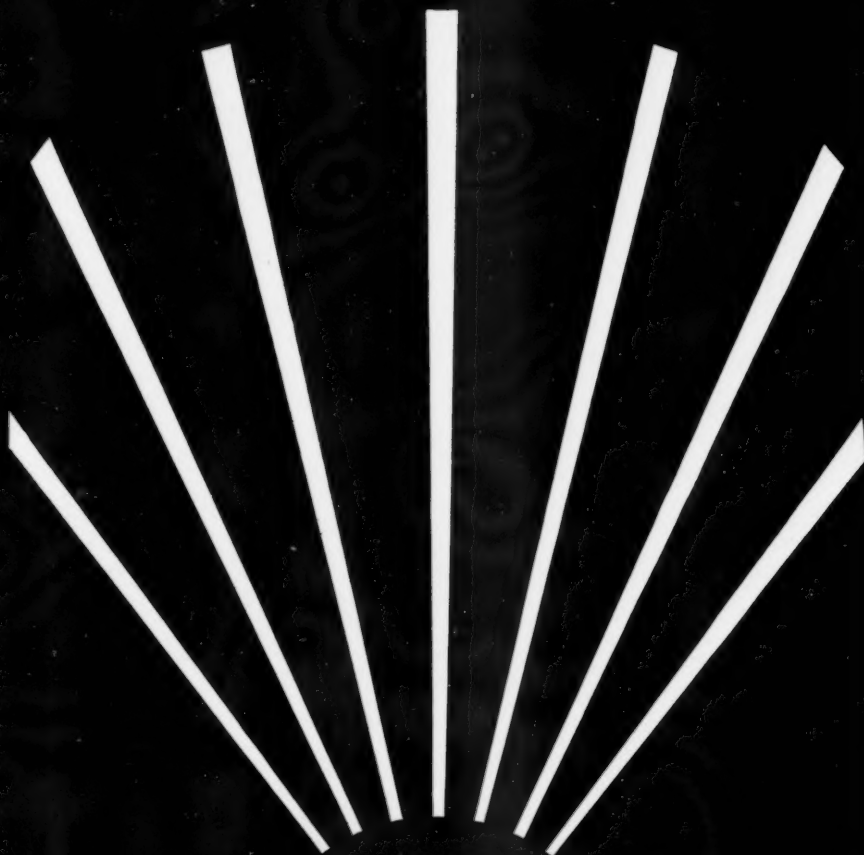
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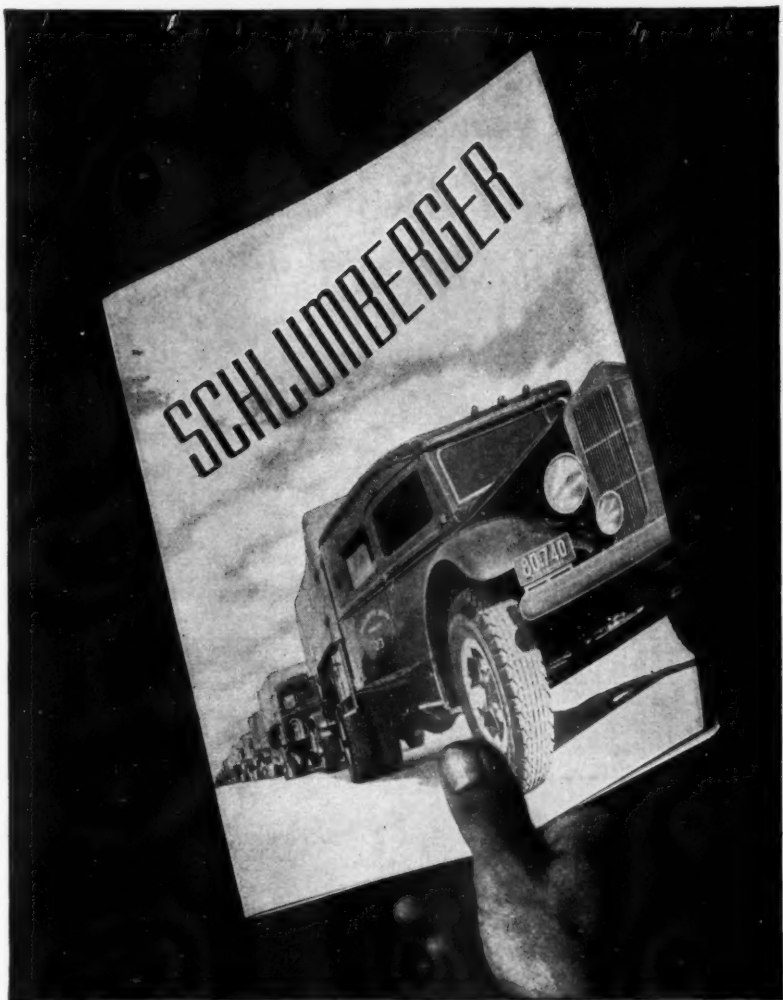
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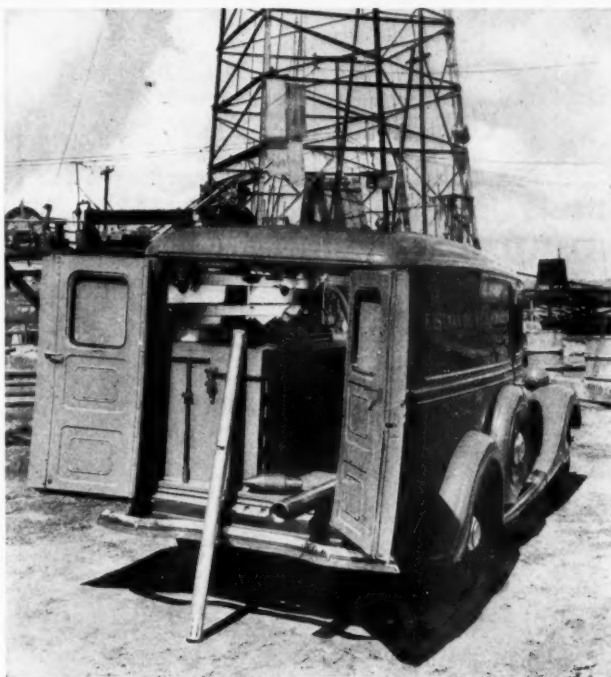
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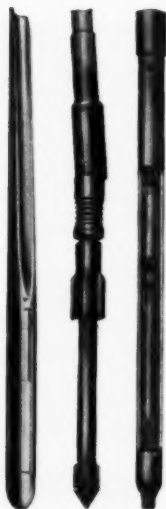
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